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NORTH OF ENGLAND INSTITUTE OF MINING ENGINEERS.

TRANSACTIONS.

VOL. 3.

1854 & 1855.

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ADVERTISEMENT.

THE Institution is not, as a body, responsible for the facts and opinions advanced in the following Papers read, and in the Abstracts of the Conversations which occurred at the Meetings during the Session.

Annual Report, &c.

In presenting their Annual Report, the Council have to congratulate the meeting on the close of the third successful year of the establishment of the Institute. There are now comprised in the roll of its members the names of gentlemen resident not only in Northumberland and Durham, but also in Yorkshire, Lancashire, Derbyshire, Staffordshire, Warwickshire, Somerset, Monmouthshire, Cumberland, Gloucestershire, Shropshire, and North and South Wales, so that the Institute represents in its own body all the principal mining districts of England and Wales. Thus has been already accomplished one of the leading and most important objects which called the Society into existence, that of establishing a communication between the several mining districts, and enabling each to acquaint itself with the peculiar, and in some cases superior, practice of the others. The meeting will probably agree with the Council that from the new species of circulation thus produced of the mining knowledge and talent of the country, the most valuable consequences may be expected to result. It is to the Institute that the initiation of a design so comprehensive is due; and a firm hope may be expressed that the Institute will continue to be the persevering and successful medium of perpetuating its own good work.

During the past year the Society, besides numerous verbal discussions on various topics, have had papers and documents read or communicated on the following subjects.

Analysis of the Strata of the Coal Formation, by H. Taylor, Esq., communicated by Thomas John Taylor, Esq.

Account of the Coal Formations of Erekli and Radosto, with Specimens, by H. G. Longridge, Esq.

The Theory of the Ventilation of Mines, by J. J. Atkinson, Esq.

On Practice of Gas at Blowers, by P. S. Reid, Esq.

Analysis of the Specimens of Coal accompanying Mr. H. G. Longridge's Paper, by Dr. Richardson.

Communications from Messrs. Grant on the subject of their Patent Safety Cages.

On the Conveyance of Coals Underground, by N. Wood, Esq., President of the Institute.

Abstract of Mr. T. Y. Hall's list of Pits in the Great Northern Coal Field.

A Vertical Section of the Coal Measures of Lanarkshire, presented by Ralph Moore, Esq.

Several Volumes of the Mining Journal, presented by William Anderson, Esq.

A Practical Treatise on Mining Engineering, presented by the Author, George C. Greenwell, Esq.

The Council recommend to the Institute the adoption of a more systematic method of reciprocating with other Scientific Institutions. The three Volumes of Transactions which will shortly be published, contain, it may fairly be affirmed, a mass of information well worthy of the notice of such Institutions, and, therefore, entitling the Society to expect an interchange. On this ground the Council advise that communications be addressed to the leading National and Continental Scientific Bodies offering to exchange publications. To a certain extent this has been already done; but not in the most effective manner, nor indeed, with the same inducements that the improved position of the Society enables it now to offer.

The Council also advise the extension of the Library of the Institute, now that rooms are prepared for its reception: and would draw attention to the resolution enabling Members to recommend books or documents to be purchased, if approved by the Council: a privilege which, it is hoped, will be more extensively used by individual Members. The Council may here mention that an opportunity is now afforded of securing a collection of the fossils of the coal formation, which is the more valuable as being the one that furnished the illustrations to "Lindley and Hutton's Fossil Flora." As this subject will be discussed in the meeting subsequently to the reading of the Report; the Council content themselves at present with drawing attention to the subject; and with expressing a hope, that this collection will not be permitted to quit the district to

which it so properly belongs, and which, they understand, is likely to be its fate, unless the Society interfere to prevent it.

The project of the establishment of a College of Mining and Manufacturing Science has been already before this society. It was also brought before the Coal Trade of these districts generally, by the diffusion of the Report read on the occasion of the last anniversary, and received the unanimous and cordial approbation of the trade at a general meeting. It was, however, of course, one of the conclusions to which the Council came, on considering the subject, that such an establishment, to be successful, must be of an enlarged and even *national* character. And as a delegation, representing the Coal Mining interests of the kingdom at large, assembled in London, in the course of the summer just passed, it was deemed a favourable opportunity for bringing the subject before that meeting, with a view to obtain their concurrence in the proposed measure. This was done, accordingly; and the subject was brought before the delegates, together with such Members of Parliament as happened to be present, by the gentlemen representing, on that occasion, the Coal Mining interests of this district.

The gentlemen present from various parts of England, connected with the Coal and Iron Mining interests, were quite alive to the strength of the motives for founding, if possible, such an institution upon a broad and firm foundation; and in accordance with this feeling, a resolution was unanimously agreed to, expressive of their concurrence in the proposed design. A committee was also appointed, composed of gentlemen representing the Mining interests, to whom the duty was allotted of making the project known in the several districts, and again meeting for the purpose of discussing and agreeing upon the necessary details, and of embodying the plan, so matured, in the shape of a Prospectus, to be submitted to the Mining and Manufacturing interests of Great Britain. Such is the position which a project, originated by this Society, and fostered by the approval of the Coal Trade of Northumberland and Durham, has taken.

For the Financial position and prospects of the Society the Council refer to the Report of the Finance Committee, and recommend the adoption of the measures which have been already adverted to, as being calculated to add to the funds of the Society, and thus to increase its means of utility.

The Council especially recommend that application be made to the owners of those collieries whose subscriptions have not yet been received.

In conclusion, the Council cannot but congratulate the Society at the close of this third year of the Institution upon the progress made by it—a progress which has extended the ramifications of the Society throughout the entire Coal Mining districts of England and Wales. Of the purposes which led to its establishment none have been lost sight of, and all have been more or less realized.

An increase of 21 members has taken place during the past year; the total number of ordinary members being now 159, and of honorary members, English and Foreign, 13.

August 2nd, 1855.

Finance Committee's Report.

31st JULY, 1855.

TO THE MEMBERS OF THE NORTHERN INSTITUTE OF MINING ENGINEERS.

GENTLEMEN,

We have much pleasure in bringing the results of the third year of the Society's operations to your notice.

It appears from the Treasurer's accounts that the cash outlay for the year ending July 31, 1855, amounts to £292 17s. 5d., and the income from various sources to £616 15s. 3d., leaving an amount in the hands of the Treasurer of £323 17s. 10d.

The liabilities, as per annexed balance sheet and general statement, would appear to amount to £58 19s. 0d., and the assets of various kinds to be of value £557 5s. 10d., leaving a balance in favour of the future of £498 6s. 10d.

We should recommend (with the view of securing the Society's property against risk of loss by fire), that such a sum be fixed upon as the probable value of its property each year, in the premises which are granted by the Coal Trade, which insurance must keep pace with the position of the Institute, as will effectually maintain it from loss such as it narrowly escaped during the past year.

We think, also, that the Minutes of the Council, with regard to the Collection of Books, should be acted upon without delay, as so few standard works upon mining are yet on the shelves of the Library.

We should also advise the publications of the Society to be more freely advertised, with view of the timely realization of assets, so as not to accumulate these matters to too great an extent.

Probably a Sub-committee, to include the Treasurer and several members of the Council, to be called the Library Committee, two of which

should be empowered to act, would be the best way of attaining this result. And we would advise that the whole care of the Society's Papers, with that of collecting fresh works of interest, Models, Specimens, &c., &c., be given to the Committee, provided that its appointment should be approved of.

Concluding with the observation that publicity is the great secret of success to an institution such as yours, we should recommend every exertion to be used in making known its objects, not only with regard to the increase of its members, but also with the view of securing the co-operation of Coal Owners from distant parts, who, both as regards the true interest of their collieries and the welfare of their workmen, are certain to become supporters of your society, when its wants and objects are more fully known and appreciated.

We believe that wherever the Institution has been spoken of, both in this country and abroad, the opinion of its efforts and aims has excited much interest, which has been unanimous in its favour.

Leaving the further elucidation of the Society's position to the able Report of the Council,

We are, Gentlemen,

Your obedient servants,

WILLIAM BARKUS,

P. S. REID,

EDW. F. BOYD, Treasurer.

THE TREASURER IN ACCOUNT WITH NORTH OF ENGLAND INSTITUTION OF MINING ENGINEERS.

1854-5.	Dr.		£	s.	d.
July 31.—	To Balance in hand from 2nd Year		258	5	9
"	Subscriptions from 133 Members to Date.....		279	6	0
"	Subscriptions collected since 1854 for that Year		27	6	0
"	Amounts received from the following Collieries, viz:—				
"	Lambton.....	£10 10 0			
"	North Hetton	6 6 0			
"	Grange	2 2 0			
"	Kepier Grange	2 2 0			
"	Seghill.....	5 5 0			
"	Cowpen	5 0 0			
"	Stella	2 2 0			
"	Barrington	3 3 0			
			36	10	0
	To Amount received from Sale of Books and other Publications		15	17	6
			616	15	3

1854-5.	Cr.	£.	s.	d.
July 31.—	By Cash paid for Postage at various times	14	1	2
"	Cash paid for Printing Society's papers	195	8	0
"	Cash paid for Circulars, Account Books, &c.	25	13	3
"	Cash paid at Anniversary Dinner, 1854	4	0	0
"	Cash paid Secretary's Salary (Mr. Sinclair)	25	0	0
"	Cash paid do. (Mr. Doubleday)	25	0	0
"	Cash paid for Books for Library	2	2	0
"	Cash paid Proprietor of Mining Journal	1	1	0
"	Cash paid do. of Newcastle Guardian	0	12	0
	By Balance in Hand.....	323	17	10
		£616	15	3

GENERAL ANNUAL STATEMENT, 1st AUGUST, 1855.

1855.	Liabilities.	£	s.	d.
July 31.—	To Amount of Reporter's Bill, unsettled, but not more than	12	12	0
"	Amount of Printer's Bills outstanding for Papers Published	16	7	0
"	Amount of Printer's Bills for Papers in hands but not completed (suppose)	30	0	0
	To Balance in favour of Society	498	6	10
		£557	5	10

1855.	Assets.	£.	s.	d.
July 31.—	By Amount of Cash in hands of Treasurer	323	17	10
"	Amount of publications sold by Mr. Weale	8	0	0
"	Do. unsold in his hands	5	12	0
"	Amount of Books, &c., unsold belonging to former years	69	4	0
"	Amount of Books unsold belonging Vol. 3	99	0	0
"	Amount of Colliery Subscriptions Uncollected	13	18	0
"	Amount of Members Subscriptions Uncollected	35	14	0
"	Donation from W. B. Wrightson Esq., ...	2	0	0
		£557	5	10

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His Grace the Duke of Northumberland.

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The Right Honourable the Earl Grey.

The Right Honourable the Earl of Durham.

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The Right Honourable Lord Ravensworth.

The Right Reverend the Lord Bishop of Durham.

The Very Reverend the Dean and Chapter of Durham.

The Venerable Archdeacon Thorpe, the Warden of Durham University.

Wentworth B. Beaumont, Esq.

GENERAL ANNUAL STATEMENT, 1st AUGUST, 1855.

1855.	Liabilities.	£	s.	d.
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"	Donation from W. B. Wrightson Esq., ...	2	0	0
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156 Woodhouse, J. T., Midland Road, Derby.
157 Walker, T. jun., High Street, Maryport.
158 Watney, A., Gwendraeth, Iron Works, Carmarthenshire.
159 Witham, Rev. Thos., Lartington Hall, Barnard Castle.

Rules.

1.—That the Members of this Society shall consist of Ordinary Members, Life Members, and Honorary Members.

2.—That the Annual Subscription of each Ordinary Member shall be £2 2s. 0d., payable in advance, and that the same shall be considered as due and payable on the first Saturday of August in each year.

3.—That all persons who shall at one time make a Donation of £20 or upwards, shall be Life Members.

4.—Honorary Members shall be persons who shall have distinguished themselves by their Literary or Scientific attainments, or made important communications to the Society.

5.—That a General Meeting of the Society shall be held on the first Thursday of every month, at 1 o'clock p.m., and the General Meeting in the month of August shall be the Annual Meeting, at which a report of the proceedings, and an abstract of the accounts of the previous year, shall be presented by the Council. A Special Meeting of the Society may be called whenever the Council shall think fit, and also on a requisition to the Council, signed by ten or more Members.

6.—No alteration shall be made in any of the Laws, Rules, or Regulations of the Society, except at the Annual General Meeting, or at a Special Meeting; and the particulars of every alteration to be then proposed shall be announced at a previous General Meeting, and inserted in its minutes, and shall be exhibited in the Society's meeting-room 14 days previously to such General Annual or Special Meeting.

7.—Every question which shall come before any Meeting of the Society shall be decided by the votes of the majority of the Ordinary and Life Members then present and voting.

8.—Persons desirous of being admitted into the Society as Ordinary or Life Members shall be proposed by three Ordinary or Life Members,

or both, at a General Meeting. The proposition shall be in writing, and signed by the proposers, and shall state the name and residence of the individual proposed, whose election shall be ballotted for at the next following General Meeting, and during the interval notice of the proposition shall be exhibited in the Society's room. Every person proposed as an Honorary Member must be recommended by at least five Members of the Society, and elected by ballot at the General Meeting next succeeding. A majority of votes shall determine every election.

9.—The Officers of the Society shall consist of a President, four Vice-Presidents, and twelve Members who shall constitute a Council for the direction and management of the affairs of the Society; and of a Treasurer, and a Secretary; all of whom shall be elected at the Annual Meeting, and shall be re-eligible. Lists containing the names of all the persons eligible having been sent by the Secretary to the respective Members, at least a month previously to the Annual Meeting;—the election shall take place by written lists, to be delivered by each voter in person to the Chairman, who shall appoint scrutineers of the lists; and the scrutiny shall commence on the conclusion of the other business of the meeting. At meetings of the Council, five shall be a quorum, and the record of the Council's proceedings shall be at all times open to the inspection of the members of the Society.

10.—The Funds of the Society shall be deposited in the hands of the Treasurer, and shall be disbursed by him, according to the direction of the Council.

11.—The Council shall have power to decide on the propriety of communicating to the Society any papers which may be received, and they shall be at liberty, when they think it desirable to do so, to direct that any paper read before the Society shall be printed. Intimation shall be given at the close of each General Meeting of the subject of the paper or papers to be read, and of the questions for discussion at the next meeting, and notice thereof shall be affixed in the Society's room 10 days previously. The reading of papers shall not be delayed beyond 3 o'clock, and if the election of members or other business should not be sooner dispatched, the President may adjourn such business until after the discussion of the subject for the day.

NORTH OF ENGLAND INSTITUTE

OF

MINING ENGINEERS.

GENERAL MEETING, THURSDAY, SEPTEMBER 7th, 1854, IN THE ROOMS OF THE INSTITUTE, WESTGATE STREET, NEWCASTLE-UPON-TYNE.

NICHOLAS WOOD, ESQ., PRESIDENT OF THE INSTITUTE, IN THE CHAIR.

Mr. DOUBLEDAY, the secretary, having read the minutes of the last general meeting, and also of the council,

The PRESIDENT said, that the first business of the meeting was the consideration of the proceedings of the Council, and the only subject which required any discussion was the recommendation made of having detached copies of the proceedings of the last meeting, together with the Report, printed separately from the volume of the proceedings of the Institute, and circulated among the members generally, and also sent to other parties who took an interest in the proceedings of the Institute; he thought it a very advisable measure, and if no observations were made on the subject, he would take a show of hands upon it. Agreed to unanimously.

Mr. T. Y. HALL moved, and Mr. T. J. TAYLOR seconded the nomination of Mr. Joseph Cowan, Blaydon Burn, as a member of the Institute.

Mr. WYNNE recommended, and Mr EDWARD SINCLAIR seconded, the nomination of Mr. Charles Jones, of Lille Hall Iron Works, and Mr. Browne, of Overseal, Ashby-de-la-Zouch, as members of the Institute.

The PRESIDENT begged to observe, for the future information of members generally, with reference to new members being proposed, that there was a rule applicable to that part of their proceedings, which was as follows,

that, "Persons desirous of being admitted into the Society as ordinary or life members, shall be proposed by three ordinary or life members, or both, at a general meeting. The proposition shall be in writing, and signed by the proposers, and shall state the name and residence of the individual proposed, whose election shall be ballotted for at the next following general meeting; and that during the interval notice of the proposition shall be exhibited in the Society's room." Heretofore they had no room to exhibit the names of parties proposed, but the Institute having now got one, he thought it was necessary that the above rule should be carried out hereafter; and that being so, they had better begin with those gentlemen who had just been proposed. He therefore suggested, that the names of those gentlemen be placed in their room, and that at the next meeting their admission be subject to a ballot.

The suggestion of the President was then assented to, and in future the names of all parties, proposed as members, will be exhibited according to rule.

The PRESIDENT next remarked, that he thought it would be in the recollection of all the members present, that at the annual meeting he stated, owing to the temporary indisposition of Mr. Taylor, the report of the Council of last year's proceedings had not been drawn up. He (the President) was glad to see Mr. Taylor among them that day, quite recovered, and in good spirits, with the Report which would then be read.

Mr. DOUBLEDAY, the secretary, then read the Report.

The PRESIDENT then moved that the Report just read be received and adopted, which was carried unanimously.

The PRESIDENT, after stating that the next subject for consideration was the Paper of Mr. T. Y. Hall, "On the Extent and Probable Duration of the Northern Coal Field," proceeded to remark, that the Institute was much indebted to Mr. Hall for his very elaborate Paper, which contained a little of every subject relating to their coal field, and comprised a selection of very useful information. He should be glad to hear any observations on it from any gentleman present. He thought discussion a subject of great importance, inasmuch as the Paper contained a maps of statistical information of every locality. It was therefore desirable that a document of this description should have the most careful consideration, so that if there appeared to be any errors in it, they might be corrected by such discussion, which would be circulated with the Paper itself. Looking at the wide and discursive nature of the communication, it was not unlikely that a few inaccuracies might exist; and, therefore, if corrected by the members acquainted with the localities, it

would render the Paper more useful. Such a course, besides being desirable, did not detract in any degree from the merits of the Paper.

Mr. HALL said, that when he was in Austria the Paper was in the printer's hands, and part of which he never had the opportunity of correcting until it was sent to him in that country. On glancing over the proofs he discovered a few inaccuracies, upon which he immediately wrote to the secretary, apprising him of them, and begged that he would lay the matter before the Council, in order that they might be corrected. Part of the errors were connected with the coal field, and others consisted of some figures misplaced opposite the names of the iron works, all of which had since been corrected. As, however, the members had got their copies, he proposed to reprint four pages containing the corrections, which, with the appendix, could be placed at the end of the Paper. Each member, therefore, before he got the entire proceedings of the year bound could easily take away the incorrect, and place the corrected pages instead of them.

The PRESIDENT here gave instructions to the secretary to transmit to every member a copy of the corrected pages; after which he proceeded to say that there were two or three statements which, being matters of opinion, he begged to make an observation or two upon. In the first place, in forming a calculation of the extent of the coal field, Mr. Hall set it forth to be 700 square miles; while Mr. Hugh Taylor made it 837 square miles; Mr. R. C. Taylor, another writer on the same subject, makes it 780 square miles. In his opinion, he was inclined to say that Mr. Hugh Taylor's estimate was the most correct, and that Mr. Hall's was too low.

MR. T. J. TAYLOR begged to observe, that the estimate of Mr. Hugh Taylor, just referred to, was made about 25 years ago, and it did not take in the portions under the sea.

The PRESIDENT resuming—Another point to which he would take the liberty of adverting, was respecting the dip and rise of the strata. Mr. Hall, in page 108, says "The coal measures slope or dip from the outcrop towards the sea, from Widdrington Castle, on the North Coast, to Castle Eden, near Hartlepool, in a south-easterly direction." And again, in page 129, "As the coal measures dip towards the sea, in a south-easterly direction from the general line of outcrop which varies in distance proceeding for the sea westward." From those quotations, an impression would be made that the strata of the coal field dipped from the westward in a south-east direction to Hartlepool and Castle Eden; that, however, was not a correct delineation of the position of the beds of the coal field. The coal field of Durham and Northumberland was, in fact,

of a basin-like shape, cut through by the line of the coast in almost the centre or nearer one edge of the basin. An inquirer standing with his back to the sea at about the mouth of the harbour at Sunderland, and looking towards Jarrow, on the Tyne, would be looking along the line of deepest depression of the strata; such line rising gradually from Sunderland towards the north and west, and from every point of that line of deepest depression the strata rises at right angles to the sea on the one hand and to the west on the other. This line of deepest depression is called the "swally," rising along its line to the north-west, and dipping towards the south-east; while, along the coast to the north, and to the south the strata rises, more rapidly to the north as being at a greater angle from the line of deepest depression, and less towards the south as being at a less angle therefrom; hence, along the line of coast on each side of this line, towards the south and west on the one side, and also towards the north and west edge of the basin on the other, the strata gradually, but regularly, (except where disturbed by dykes or faults) rises and crops out to the surface, or into the super-incumbent, unconformable, magnesian limestone.

Mr. HALL—I made a similar remark in my Paper, excepting that I went a little further south than the President. I know the seam begins to rise south as stated, but then there must be a level from that point to Ryhope, which I consider to be the deepest.

The PRESIDENT replied, that he did not find in Mr. Hall's description any allusion to this.

Mr. HALL—Because he would find it in the Appendix.

The PRESIDENT—The appendix has not yet been circulated, but the deepest part of the coal field was certainly between Monkwearmouth and Ryhope, and from that point as a centre, it radiated north-west, and south from the sea-coast; but how far the basin continued into the sea was not yet ascertained. But the deepest known point was near Monkwearmouth.

Mr. BARKUS—On the north-side of the river the coal was very flat and appeared to be the bottom of the basin, and probably it was, as it took its rise from that point to the sea.

Mr. BOYD—There was a rise towards the sea from South Shields.

Mr. T. J. TAYLOR—A calculation had been made in the sinking at Ryhope for a rise in that direction from Wearmouth.

The PRESIDENT—It was not a correct basin, as there was a "swally" from Wearmouth, passing through Jarrow Slake until it came to the Great Dyke; crossing which there was a continuation of the "swally," but not quite in the same direction.

Mr. T. J. TAYLOR supposed that that might be attributable to a local alteration of the Dyke.

Mr. HALL—The estimate I made dipped towards Monkwearmouth.

Mr. T. J. TAYLOR thought the deepest point was not at Monkwearmouth, but further east.

Mr. HALL—That is exactly my view of the subject.

The PRESIDENT—Certainly, but every part of Ryhope was at a less depth than Monkwearmouth.

Mr. HALL—But Mr. Taylor and Mr Forster thought different, as well as himself.

The PRESIDENT certainly was sorry to differ from three gentlemen of such acknowledged talents. All that he felt anxious about was that the most correctly ascertained facts should go forth in the proceedings of the Institute. He was quite sure that such an interchange of opinions would not detract from the merits of Mr. Hall's Paper; they might be the means of making it more accurate and useful. Another point to which he would next allude was with reference to the Dykes, which, on the map, were generally extremely correct, but there were some little inaccuracies. With respect to the Butterknowle Dyke, the Gordon Colliery was on the north-side of it, while the plan showed it as on the south-side. Also, as regards Westerton Colliery, which was about 200 yards south of the Dyke, while on the plan it was about the same distance north of it. Such inaccuracies, upon the whole, were not numerous, but it was desirable they should be pointed out. In looking over the map, another matter also took his attention, which was the distribution of the districts into different descriptions of coal, an object of great importance, as it would tend to convey information to parties at a distance, but this the map failed to give. He perceived that the household coals of the Tyne were laid down as existing only on the north-side of the Great Dyke, while on the south-side (designated No. 4), and where household coals had existed in the greatest perfection, Mr. Hall had omitted to colour that as household coal. He alluded particularly to the Wallsend district.

Mr. HALL replied, that he considered it of no use shading that part of the Map, as all the household coals at the best seams at Wallsend and other collieries connected with that portion of the coal field had been worked off.

The PRESIDENT, however, thought it ought not to be allowed to go abroad that the famous Wallsend district had been neglected. Again,

he also thought that it would have been better to have enumerated and distinguished the characteristics of the coal field by seams rather than by the different qualities of the coal. Take the Hutton seam for instance. In the southern part of the coal field the Hutton seam was the best household coal, as at Hetton, Haswell, Stewart's, &c. Proceeding northward until they came to the north side of the Wear, it became the best gas coal as at Springwell, Heworth, Usworth, &c. Further north it became the best steam coal, as at Cramlington, Seghill, Cowpen, &c. From thence at right angles they might pursue their examination into the coking district, as at Marley Hill, where it became a coking coal, in each of which places it was famous for the particular quality of the particular locality, but in no one locality did it partake of all the different qualities. Then the High Main seam never varied in quality, wherever it was found its quality was a household coal, from Earsdon at the extreme north. Southwards to Wallsend, Hebburn, and to the Wear, still its character was the same. Then the same was the case with the Bensham seam, as at Harton and Hilda and southward all the way from Monkwearmouth to Ryhope and Seaham; so that although the household coals were coloured on the map as confined to the north-side of the Great Dyke, yet in reality they extended from Earsdon on the north into the Seaton and extreme southern district, throughout the whole extent of the coal field, so that if some explanation had not been given an erroneous impression would be produced by parties supposing that the household coals were limited to the colours on the plan. The same remarks might apply to the coking district. There was a seam at Thornley colliery, in the Hartlepool district, which was used as a coking coal, called the "Harvey Seam." The same seam exists at Whitworth and Byer's Green, and on the Tees, while the name was given to this seam on the Tyne where it was also a coking coal. This quality of coal could, therefore, scarcely be said to exist in any particular district, as it seemed to extend through districts where both gas and household coals existed. He, therefore, was inclined to think that it would have been better if the separate seams had been delineated rather than the divisions into the different qualities adopted on the plan. He trusted that some member of the Institute would be induced to furnish the society with a series of maps coloured in seams, in the manner described.

Mr. T. J. Taylor thought such a plan could not be given unless one plan was devoted to each seam or bed of Coal.

The President again remarked how much the Institution was indebted to Mr. Hall, as he had laid the foundation of an attempt to delineate

the different descriptions of coal in the coal field, but which were too numerous to be sketched clearly and distinctly on one plan.

Mr. Hall begged to say that instead of the various plans for the different seams, he was preparing sections similar to what was alluded to in chap. XIV, to enable him to complete a model of the north coal field. The Appendix, then in the printer's hand, would give a further description, with the numerous levels of stations and pits; and thus, with what they already proposed, together with the government levels, a model might be made pretty complete. Nothing else but a model could describe the coal field.

Mr. T. J. Taylor here introduced a stranger from the West Riding of Yorkshire, whom he thought would offer a few remarks on the present subject.—The gentleman's name is Mr. Hartop.

Mr. Hartop then rose, and addressed the meeting.—He observed that as Mr. Taylor had alluded to him as a stranger, and also perceiving the great interest taken in the subject alluded to by the President and others, perhaps a few observations from him might tend to throw some light on the subject. If he were allowed to refer to the Yorkshire coal field, he flattered himself that he could clearly show that they were in a similar condition to their own district. He read a Paper twelve years ago which tended to remove the idea that coals lay in basins in large quantities: for it so happened that he had the direct management of various coal and iron mines in Derbyshire and Yorkshire, up to the magnesian limestone above Leeds. He therefore was conversant with that entire district, and could show then the advantages of tracing coal and ironstone by the water level, particularly in the mountainous districts. Mr. Hartop then entered at some length into an explanation of the results of tracing the water levels in Yorkshire, but as he illustrated his observations by occasional diagrams formed hastily on the table, it was impossible to give his remarks consecutively. He however was understood to attempt to prove that the Yorkshire coal field was not a basin but that it was a continuous coal field, extending itself northwards until it connected itself with the Great Northern Coal Field of Durham.

The President, as well as Mr. Taylor, doubted the position of Mr. Hartop as being able to form a continuous connection between the two coal fields, but if he could prove it they would be very glad to have a paper on the subject from him, which would be highly acceptable to the Institute.

The President then observed that they were much indebted to Mr. Hartop for his remarks, and hoped that he would be induced to favour the Institute with a paper on the Yorkshire coal field.

Mr. HARTOP had already published a paper on the subject, which was in the Yorkshire Geological Society.

The PRESIDENT called attention to the paper of Mr. Hedley, but as that gentleman was not present he thought it advisable to postpone the discussion upon it. Any remarks on Mr. Greenwell's paper he supposed also, must be postponed for the same reason.

Mr. T. J. TAYLOR then read the following paper "On the Analysis of Rocks," by Hugh Taylor, Esq., Cramlington.

The meeting then adjourned until the first Thursday in October.

ANALYSES OF ROCKS

OF THE

COAL FORMATION.

BY HUGH TAYLOR, Esq., CRAMLINGTON.

COMMUNICATED TO THE INSTITUTE BY

MR. T. JOHN TAYLOR.

Up to a very recent period the attention of geologists has scarcely been directed to the facts which chemi-try is capable of supplying in support of the doctrines of their science, although it admits of no doubt that the analysis of rocks and comparison of their chemical characters may, in many instances, materially contribute to the solution of its problems, or to the determination of disputed points. Of late, however, the chemical investigation of the volcanic rocks of Iceland and of some other districts has led to interesting results, and though the stratified rocks in some respects afford a less promising field of inquiry, much valuable information may be derived from a knowledge of their chemical composition.* In regard to this class of rocks, we are still almost entirely destitute of chemical information; and, under these circumstances, I venture to hope that the following analyses of the rocks of the coal formation may not be without value, in so far as, to the best of my knowledge, none of them—with the exception of coal itself—have yet been analysed. The analyses were made in the laboratory of Dr. Anderson of Edinburgh, to whose kind assistance and encouragement I have been much indebted during their prosecution.

The rocks analysed were taken principally from Buddle's Hartley

* We recommend to the particular attention of students of the chemistry of rocks the many valuable memoirs of Mr. M. A. Delesse in the Annales des Mines, &c.; and also the important Lehrbuch der Chemischen und Physikalischen Geologie of the celebrated Dr. Gustav Bischof.—*Edit. of Edin. Phil. Jour.*

Colliery in the Newcastle coal field, and, though few in number, are calculated to throw more light on the general constitution of such rocks than might be at first sight expected, each specimen being selected as the type of a family, the members of which differ little in their physical or chemical properties; so much so, indeed, that no difficulty exists in referring any individual stratum to the family to which it belongs.

On examining the section of the coal field, a certain definite arrangement of the beds is apparent, and a tendency to the repetition of small groups of strata—each group consisting of the same, or nearly the same, series of rocks. The succession of the members of those groups is, of course, liable to a certain amount of variation, individual beds sometimes disappearing or "cropping out"—and so destroying the uniformity of the series; but it may be observed generally that each seam of coal is the centre of a group, and is enclosed above and below by a succession of strata more or less impregnated by a bituminous or coaly matter, those in immediate contact with the coal partaking so much of its character as to be capable of undergoing combustion, which in receding from it they become gradually more and more earthy, until eventually all trace of organic matter is lost.

The succession of the rocks in each group, taking them in the most general point of view, is as follows, in descending order :—

Fire-clay or Thill.
Sandstone.
Blue shale.
Bituminous shale
Coarse coal (sometimes Cannel).
Coal.
Coarse coal.
Fire-clay.

This succession, as already observed, is not absolutely invariable, for even sandstone is occasionally found in contact with the coal, and other strata (as clay iron-stone for instance) are sometimes associated with the foregoing, whilst in other instances one or more members of the group are entirely wanting. But these are exceptional cases, the arrangement in the majority of instances being that which I have given above. The rocks employed for analysis were as far as possible selected from one group, and embrace all its characteristic members, so that from the analysis of these few substances we have a tolerably correct idea of the composition of the rocks of the whole formation.

The actual order of superposition of the specimens analysed is as fol-

lows:—The order is ascending, and figures are attached to the strata analysed.

	Feet.	In.	
1. Fire-clay (or Thill) . .	2	0	in thickness
Coarse coal . . .	0	7	"
2. Good coal . . .	5	2	"
3. Coarse coal . . .	0	3	"
4. Bituminous shale . .	3	2	"
5. Blue shale, or slate-clay .	3	1	"
6. Micaceous sandstone . .	0	7	"
Blue shale (again) . .	0	10	"
Sandstone (again) . .	0	7	"
Blue shale, inclosing nodules of ironstone . .	2	1	"
Bituminous shale and coal .	0	6	"
Ironstone with shells . .	1	11	"
7. Muscle-bind . . .	0	6	"

Before entering upon the details, it may be desirable to glance at the methods of analysis.

Carbon and *Hydrogen* were determined by combustion with chromate of lead, copper turnings being made use of for the deoxidation of any nitrous acid formed during the process. *Nitrogen* by Warrentrap and Wills' method. The *Sulphur* was determined by deflagrating the substance with pure nitrate of potash and carbonate of soda, precipitating with chloride of barium, and calculating the sulphur from the sulphate of baryta obtained. *Ash* of coals by complete ignition in a platinum crucible. The *Inorganic substances* were estimated in the hydrochloric acid solution. The portion not soluble in acids (or a substance in the first instance only slightly affected by them) was fused with a mixture of carbonates of potash and soda, and the analysis conducted in the usual manner. The alkalies were determined in some instances by fusion with carbonate of baryta, in others by attacking the substance with hydrofluoric acid. The carbonic acid was determined in the ordinary way. All the substances were dried at 212°; and in those which contained no organic matter the water of combination was determined by ignition.

The details of the analyses are as follows:—

No. 1. *Fire-clay.*—Sp. gr. 2·519, of a grey colour, streak dull, very soapy to the touch. It constitutes usually the basement of each coal seam. As that from "Buddle's Hartley" was not a fine specimen, one was taken from the base of the coal at Blaydon Burn Colliery in Tyneside, where it is made use of for the manufacture of fire-bricks, &c.

Composition.

Water of combination	10·524
Lime	·668
Magnesia	·746
Peroxide of iron	2·008
Alumina	27·753
Potash	2·189
Chloride of sodium and sulphate of soda	·439
Silicic acid	55·500
	99·827

No. 2. *Good Coal.*—Sp. gr. 1·259, fracture conchoidal. Interspersed rather abundantly with iron pyrites; depth from surface 64 fathoms; is from the "Low main seam," principally used for steam purposes, to which end it is largely exported.

Composition.

Carbon	78·690
Hydrogen	6·000
Nitrogen	2·370
Oxygen	10·068
Sulphur	1·509
Ash	1·363
	100·000

Ash of the above.

Peroxide of iron	14·237
Alumina	10·883
Lime	8·915
Magnesia	1·010
Potash	1·039
Chlorine, *traces*	
Sulphuric acid	8·210
Silicic acid	53·151
Unburnt charcoal	2·657
	100·102

No. 3. *Coarse Coal.*—Sp. gr. 1·269; fracture slaty; lies immediately over the good coal; and the bed varies from two to six inches in thickness. It contains a large amount of iron pyrites, and is put to no useful purpose.

Composition.

Carbon	70·307
Hydrogen	4·714
Nitrogen	1·446
Oxygen	5·433
Sulphur	1·236
Ash	16·864
	100·000

Ash of the above.

Soluble in Acids.	Lime	1·286	
	Magnesia	0·420	
	Iron	2·187	
	Alumina	21·231	
	Potash	2·200	
	Soda, *traces*		
	Sulphuric acid	1·705	
	Silicic acid	1·118	
			30·147
Insoluble in Acids	Lime, *traces*		
	Magnesia	0·662	
	Iron, *traces*		
	Alumina	6·530	
	Silicic acid	60·812	
	Unburnt charcoal and loss	1·849	
			69·853
			100·000

No. 4. *Bituminous Shale.*—Sp. gr. 1·860; rests on coarse coal; two to three inches in thickness; black, hard, and brittle, of a slaty structure; contains impressions of the Flora of the period.

Composition.

Carbon	26·700
Hydrogen	2·630
Oxygen	9.090
Nitrogen	·934
Lime	1·027
Magnesia	·519
Protoxide of iron	4·275
Alumina	19·347
Potash	·839
Soda	·374
Chlorine, *traces*	
Silicic acid	34·276
	100·011

No. 5. *Blue Shale* (Slate-clay).—Sp. gr. 2·536; in thickness about three feet; of a bluish-grey colour; is of a much more earthy appearance than last, on which it rests; is softer and not so slaty, and is studded with nodules of ironstone. Is nearly related to the fire-clay, both in composition and physical properties.

Composition.

Water of combination - -	11·083
Lime - - - -	0·595
Magnesia - - - -	1·377
Peroxide of iron - - -	4·569
Protoxide of iron - - -	4·545
Alumina - - . -	23·290
Potash - - - -	2·089
Chloride of sodium, *traces*	
Sulphuric acid, *traces*	
Silicic acid - - - -	52·452
	100·000

No. 6. *Micaceous Sandstone.*—Sp. gr. 2·598, over last, varying from six inches to six feet in thickness; of a fine white colour, close-grained, and with small plates of mica, very conspicuously seen.

Composition.

Water of combination - - -	6·888
Peroxide of iron - - -	9·539
Alumina - - - -	8·126
Lime - - - -	1·112
Magnesia - - - -	0·325
Potash - - - -	1·655
Soda - - - -	1·859
Silicic acid - - - -	70·257
	99·761

No. 7. *Muscle-Bind.*—Sp. gr. 2·592; in thickness, six inches; is a clay-ironstone, thickly embedded with indurated shells of a brown colour, and very brittle. This bed resembles the muscle-bind of the Derbyshire and Yorkshire coal-fields; and is found also in the coal-fields of Scotland. It lies, in this instance, at the depth of 62 fathoms from the surface, or 9½ feet above the "Low-main coal."

Composition.

Soluble in Acids.	Organic matter and water of combination	11·221	
	Protoxide of iron - - -	18 637	
	Manganese, *traces*		
	Alumina - - - -	1·194	
	Lime - - - -	4·084	
	Magnesia - - - -	1·078	
	Chloride of sodium, *traces*		
	Potash - - - -	1·319	
	Silicic acid, *traces*		
	Carbonic acid - - -	14·057	
			51·590
Insoluble in Acids.	Oxide of iron. *traces*		
	Alumina - - - -	16·292	
	Lime - - - -	0·988	
	Magnesia - - - -	0·288	
	Silicic acid - - - -	31·068	
			48·636
			100·226

No. 8. *Cannel Coal.*—Sp. gr. 1·319; is a black, homogenous mass, hard, brittle, and capable of taking a fine polish; fracture conchoidal. Though not in the section of "Buddle's Hartley," is often found in connection with the coal, as roof, base, or even interstratified with it; that analysed is a fine specimen from "Blaydon Main" colliery, in Tyneside.

Composition.

Carbon - - - -	78·056
Hydrogen - - - -	5·805
Nitrogen - - - -	1·854
Oxygen - - - -	3·119
Sulphur - - - -	2·223
Ash - - - -	8·943
	100·000

A comparative view of these analyses leads to some interesting results, and appears to indicate a pretty close connection between some of the members of the coal formation.

Comparing the organic constituents of the different coals and bituminous shale, it will be observed that they so far resemble one another, as all to contain carbon, hydrogen, nitrogen, and oxygen, and a general similarity is apparent in the quantitative relations of these elements. But this relation is to a great extent concealed by the variable proportion of inorganic matter which the substances contain, and becomes much more striking when the ash is substracted, and the composition of the organic part calculated on 100 parts. When this is done, we obtain the following numbers :—

	Coal.	Coarse Coal.	Cannel Coal	Bituminous Shale.
Carbon -	81·01	85·83	87·36	67·84
Hydrogen -	6·17	5·75	6·53	6·68
Nitrogen -	2·44	1·76	2·09	2·37
Oxygen -	10·38	6·66	2·53	23·11
	100·00	100·00	100·00	100·00

From these numbers it appears that all these substances present a pretty close resemblance, except the organic matter of the bituminous shale, which is very much richer in oxygen than any of the others. This difference, however, is more apparent than real, and I believe it to depend upon the method of analysis employed, by which any water which may exist in combination with the inorganic constituents, comes to be determined along with, and reckoned as part of the organic matter. I I shall have occasion, in discussing the inorganic constituents of the rocks, to show that the inorganic part of the bituminous shale does in all pro-

bability contain water, the exact amount of which cannot, in presence of organic matter, be determined by analysis, but which, from other considerations, would appear to amount to about 6·6 per cent. If we therefore subtract from the organic matter of the shale the quantities of hydrogen and oxygen corresponding to 6·6 per cent. of water, and then calculate the result upon one hundred parts, we obtain the following numbers, which agree in a remarkable manner with those obtained from the good coal.

Carbon	81·62
Hydrogen	5·78
Nitrogen	2·84
Oxygen	9·76
	100·00

These analyses may then be considered as establishing the fact, that the organic matter which permeates the strata of the coal-formation is chemically identical with coal itself; in fact, that bituminous shale differs in no respect from coal, except in containing a largely preponderating amount of ash, and that whatever may have been the manner in which coal has been formed, bituminous shale must be produced under precisely similar circumstances. The analyses appear, however, further to indicate the existence in the coal field of vegetable matter in two different phases of decomposition, for the cannel and coarse coals contain a very much larger amount of carbon, and smaller of oxygen, than the other two, which approximate very closely to one another in composition. Now the gradual decomposition of vegetable matter is attended by the gradual diminution of the oxygen present, carbonic acid, which for every six parts of carbon carries off 22 of oxygen, being gradually evolved, and it is fair to admit that the composition of the good coal and organic matter of the bituminous shale, indicates a less advanced state of decomposition than that of the other two; and as it must be manifest that all are exposed to the same causes of decomposition now, the difference which is observed must be due to causes operating before the deposition of the superincumbent strata.

The analyses of the inorganic constituents of the different rocks also afford evidence of a certain connection among the different members of the formation, though it is less obvious both on account of their greater complexity and the certainty of their being, in some instances, mere mechanical mixtures, liable to great variations. If, however, we compare only that portion of certain of these substances which is insoluble in acids, and which analysis shows to be of constant composition, we arrive at

some interesting conclusions. The whole of the fire-clay, with the exception of small quantities of lime and potash, is insoluble in acids. Now, the clays already known to us, are definite mineral compounds, presenting an invariable composition. Porcelain clay, for instance, is a hydrated sesquisilicate of alumina represented by the formula $2Al_2\ O_3\ 3Si\ O_3 + 3HO$, and the same composition is found in all our purer clays, and the fire-clay of the coal formation is also a definite silicate, though not identical with porcelain-clay, its composition, setting aside as non-essential the small quantities of lime and potash, corresponding very closely with the formula $Al_2\ O_3\ 2Si, O_3 + 2HO$. Now, the same clay can be traced in other members of the coal formation; thus the muscle-bind is a mixture of this silicate with carbonates of iron and lime. This connection is not seen as the analysis stands, but becomes apparent by comparing the fire-clay, calculated as anhydrous, and the insoluble matter of the muscle-bind calculated to 100 parts.

	Fire-clay.	Insoluble matter of musle-bind.
Silicic acid - -	62·14	63·89
Alumina - -	31·07	33·49
Peroxide of iron -	2·24	..
Lime - -	0·74	2·01
Magnesia - -	0.83	0·61
Potash - -	2·45	..
	100·00	100·00

Here the sole difference appears to be that, in the fire-clay, a small quantity of alumina is replaced by the isomorphous peroxide of iron, and both lead to the same formula $Al_2\ O_3\ 2Si\ O_3$. This represents both substances as anhydrous, but the fire-clay contains water in combination, corresponding, as before observed, to two equivalents, and it admits of no doubt that the insoluble matter of the muscle-bind, as it exists in the rock, is also hydrated, although, from the presence of organic matter, it is impossible to determine the amount of water in an accurate manner. An attempt was however made to determine the quantity of water by gently heating the substance so as to avoid decomposing the organic matter; and in this way 3·08 per cent. of water was obtained, but obviously no reliance can be placed upon this as a quantitative determination, because it was impossible to obtain sufficient heat to expel the whole of the water without destroying the organic matter, but it is sufficient to establish the fact that water actually was present.

The blue shale and inorganic matter of the bituminous shale, form another pair very similar to one another, though different from the fire-

clay. In order to render this similarity apparent, I give the results of the analyses calculated, the blue shale as anhydrous, and the inorganic matter of the bituminous shale in 100 parts.

	Blue shale.	Bituminous shale.
Silicic acid - -	58·99	56·51
Alumina - -	26·19	31·89
Peroxide of iron -	5·14	..
Protoxide of iron -	5·11	7·04
Lime - - -	0·67	1·69
Magnesia - -	1·54	0·85
Potash - - -	2·34	1·38
Soda - - -	..	0·61
	100·00	100·00

In these two substances, in addition to silicic acid and alumina, we have a large amount of bases with one equivalent of oxygen, among which protoxide of iron and potash predominate. The relation of silica to the sesquiatomic bases is the same in both, alumina in the blue shale, being in part replaced by peroxide of iron, and though the quantity of monatomic bases in the bituminous shale considerably exceeds that in the blue shale, still the similarity of the two is sufficiently striking. It will be observed that, in the above calculation, both substances are represented as anhydrous, while the blue shale actually contains 11 per cent. of water. I infer, however, from the analogy of the two substances, that the inorganic matter of the bituminous shale must also be a hydrated compound, containing the same proportion of water which I have accordingly supposed it to be in the calculation of the constitution of its organic part, given in page 147 of the "Edinburgh New Philosophical Journal," for Jan., 1851.

The inorganic matter of the other rocks is too various to admit of any conclusions being drawn regarding their constitution, although they present some points of interest, which, however, I shall not at present attempt to discuss.

In conclusion, I may be permitted to hope, that the results of these analyses are sufficiently interesting to lead others into the same field of inquiry, and that from the accumulation of facts we may eventually be led to some general laws regulating the deposition of the stratified rocks.

NOTE.—(By the Author.)

The minerals of which analyses are given in the following paper (with the exception of the coals), seem to be a mere mixture of various substances; their composition, therefore, is not sufficiently definite to be capable of expression by means of formulæ. But for those substances insoluble in acids, the purity of which can be more safely calculated on,

formulæ are given below, though not so much with the expectation of exhibiting their true composition, as of thus affording a more ready means of comparison. Formulæ for—

Fire clay	$KO, SiO_3 + 2\ Al_2O_3, 5\ SiO_3 + 4\ HO$
Slate clay	$KO, SiO_3 + 2\ Al_2O_3, 4\ SiO_3 + 5\ HO$
Micaceous sandstone	$CaO, SiO_3 + 2\ Al_2O_3, 8\ SiO_3 + 6\ HO$
Insoluble matter of muscle-bind	$CaO, SiO_3 + 2\ Al_2O_3, 5\ SiO_3$
Insoluble matter of coarse coal	$Al_2O_3, 12\ SiO_3$
Insoluble matter of bituminous shale	$FeO, SiO_3 + 2Al_2O_3, 4SiO_3$

It is not to be supposed that the silicates have the exact constitution here given, but simply that these are the results afforded by calculating the per-centages. Nor does the base of each silicate consist wholly of the constituent above given, for the constituent in greatest quantity gave its name to the base. Some of the silicates are represented with *water of combination,* others without it, but no conclusion is to be drawn from this circumstance, as the silicates apparently anhydrous were ignited previous to analysis, and would therefore give off their water of combination.

The foregoing analyses were made by Mr. Hugh Taylor, while studying chemistry in the laboratory of Dr. Anderson, of Edinburgh.

Those which follow, not being yet made public, are to be viewed as an original communication, which I have much pleasure in making in the author's name.

Like the previous analyses, these also have been made with the greatest degree of care, and without reference to time or expence. They may therefore be safely considered as accurate, according to existing chemical views and methods.

The most remarkable results are perhaps those showing the alteration in the chemical composition of coal as it approaches a whin dike, the particular locality being, in this case, that of Shotton colliery, exhibiting analyses of the cindered coal adjoining the dike, and of the coal sixty-three yards from the dike, as compared with the Haswell Hutton seam in an unaltered state.

I have inserted, by way of note to those analyses, the constituents of Anthracite from Coalbrook Dale and from Pembrokeshire, on a comparison with which it appears that the coal at sixty-three yards from the whin dyke, and before it becomes cindered, may be classed as an An-

thracite. This is a curious fact, and naturally suggests that the formation of Anthracite is due to an action upon Bituminous Coal, similar to the one which has taken place in the vicinity of the igneous rock under consideration.

The quantity of Carbonate of Magnesia in one of the analyses of Carboniferous Limestone (Holy Island) is remarkable, being upwards of 35 per cent. On the contrary the bed, called the White Bed of the Whitley Magnesian Limestone, is almost a pure Carbonate of Lime, containing much less than 1 per cent. of Magnesia. Circumstances like these show the inadequacy of our present system of generalization, and how much they require to be modified to make them correspond with the actual operations of nature.

Analysis.

1. Waste Heap, Buddle's West Hartley.

The sample analysed was a reddish powder, obtained by screening a considerable quantity of heap; clinkers and stones are, therefore, not included.

Soluble in Wat.	Water of combination	1·750	
	Lime	4·376	
	Magnesia	·843	
	Potash	·188	
	Chloride of sodium	·063	
	Sulphuric acid	7·538	
			14·758
Soluble in Acids.	Organic matter	·922	
	Peroxide of iron	8·780	
	Alumina	6·970	
	Lime	1·740	
	Magnesia	·789	
	Potash	·092	
	Soda	·588	
	Sulphuret of iron, *trace*		
	Carbonic acid	·265	
	Silica	·189	
			20·335
Insoluble in Acids.	Peroxide of iron	9·512	
	Alumina	11·473	
	Lime	·271	
	Magnesia	·456	
	Potash	·935	
	Soda	·172	
	Silica	41·833	
			64·652
			99·754

2. ANALYSES OF COAL FROM HUTTON SEAM, SHOTTON AND HASWELL COLLIERIES. *Effect of Whin Dike.*

	Cinder Coal, adjoining Dike.		Coal, 63 Yards from Dike.*		Haswell Hutton Seam.	
	Including Ash.	Deducting Ash.	Including Ash.	Deducting Ash.	Including Ash.	Deducting Ash.
Carbon -	80·255	92·888	89·916	91·768	84·284	84·890
Hydrogen -	2·405	2·783	3·441	3·511	5·522	5·561
Nitrogen -	1·170	1·354	2·129	2·172	2·075	2·089
Oxygen -	·923	1·068	1·228	1·253	6·223	6·267
Sulphur -	1·646	1·905	1·267	1·293	1·181	1·189
Ash -	13·601		2·019		·715	
	100·000		100·000		100·000	

* Analysis of *Anthracite*, for comparison :—

A from Coalbrook Dale, by Jacquelin.

B from Pembrokeshire, by Sehafhautl.

	A	B	Mean of the Two.
Carbon	90·58	94·10	92·34
Hydrogen	3·60	2·39	3·00
Nitrogen	0·29	0·87	0·58
Oxygen	3·81	1·34	2·57
Sulphur is not noticed, if any			
Ash	1·72	1·30	1.51
	100·	100·	100·

3—ANALYSIS OF COKE MANUFACTURED BY MR. J. MORRISON, FENCE HOUSES, DURHAM, UNDER M. BARBE'S PATENT, THE IMPURITIES BEING SEPARATED FROM THE "DUST COAL," BY WASHING.

	From Hutton Seam.	From Low Main Seam.
Carbon - -	93·150	91·658
Hydrogen - -	·721	·708
Oxygen, Nitrogen -	·905	1·296
Sulphur - -	1·276	1·183
Ash - -	3·948	5·155
	100·000	100·000

4.—Analysis of Hobberlaw (Carboniferous) Limestone, Alnwick.

Carbonate of Lime - - -	96·986
Carbonate of Magnesia - - -	1·006
Peroxide of Iron and Alumina - -	·590
Sand - - - - -	1·209
	99·791

5.—Analysis of Carboniferous Limestone, North Sunderland.

Carbonate of Lime - - -	96·637
Carbonate of Magnesia . - -	1·938
Peroxide of Iron and Alumina - -	·526
Sand - - - - -	·707
	99·808

6.—Analysis of Holy Island (Carboniferous) Limestone. (Top-bed.)

Carbonate of Lime - - -	59·280
Carbonate of Magnesia - - -	35·121
Iron and Alumina - - -	3·746
Sand - - - - -	1·384
	99.531

7.—Ditto Bottom-bed.

Carbonate of Lime - - -	96·234
Carbonate of Magnesia - -	2·076
Iron and Alumina - - -	·242
Sand - - - - -	1·273
	99·825

8.—Analysis of Ironstone from Cleveland.

Sample analysed was from Eston Nab, Cleveland Hills, Yorkshire, the bed being 16 feet in thickness, and apparently of the same quality throughout.

Lime - - - - -		5·803
Magnesia - - - -		3·504
Protoxide of Iron	Metallic Iron 36·951 Oxygen 10·867	47·818
Manganese—*traces* - - -		.....
Alumina - - - -		6·499
Chloride of Potassium, with a little Chloride of Sodium -		1·052
Sulphuric Acid—*traces* - -		.....
Carbonic Acid - - -		24·939
Silicic Acid - - - -		7·257
Water of Combination and a little organic matter - -		3·151
		100·023

ABOVE COMBINED (?).

Carbonate of Lime			10·292
Carbonate of Magnesia			7·228
Carbonate of Iron			43·487
Silicate and Aluminate of Iron.	Peroxide of Iron	21·057	37·964
	Alumina	6·499	
	Silica	7·257	
	Water of Combination	3·151	
Chlorides of Potassium and Sodium			1·052
			100·023

NORTH OF ENGLAND INSTITUTE

OF

MINING ENGINEERS.

MONTHLY MEETING, THURSDAY, OCTOBER 5th, 1854, IN THE ROOMS OF THE INSTITUTE, WESTGATE STREET, NEWCASTLE-UPON-TYNE.

NICHOLAS WOOD, ESQ., PRESIDENT OF THE INSTITUTE, IN THE CHAIR.

The minutes of the Council having been read by the Secretary,

The PRESIDENT begged to call attention to the large accumulation of books which lay at present useless in the Institute, several gentlemen had spoken to him of the difficulty they had in obtaining a copy of the proceedings. He, therefore, thought it would be advisable to place their books in the hands of some London publisher, with a view of advertising them, so that parties wanting them may have no difficulty hereafter in getting copies, as they would then know where they were to be had. If, therefore, it met the approbation of the meeting, as he would be in London in a short time, he would endeavour to make some such arrangement with some of the London publishers.

Several members having expressed their hearty concurrence in such a course, the suggestion of the President was at once adopted.

The PRESIDENT next informed the meeting that the reason the members had not got the last paper of the year's proceedings arose from the circumstance of Mr. Hall's paper being much longer than at first intended, but he was glad to say that it was now all printed, and would be in the hands of the members by Monday first.

The following members, who had been proposed at the last monthly meeting were ballotted for, and unanimously elected, viz:—Mr. Joseph

Cowan, Blaydon Burn; Mr. Edward Jones, Lilleshall Iron Works, Shiffnal, Salop; and Mr. John Browne, Overseal, Ashby-de-la-Zouch.

Several new members were proposed for ballot at the next meeting.

The PRESIDENT then said that they were promised last month a paper by Mr. P. S. Reid, but as that gentleman had been prevented from illness in completing his paper, and was unable to attend, they would not have the paper until the next meeting. There were, however, two papers before them for discussion, and there was also the Appendix to the Northern Coal Field, by Mr. Hall, which, although printed, had never been read at the Institute. One of the papers deferred was Mr. Greenwell's on the East Somersetshire Coal Field, and the other, Mr. Hedley's paper. He supposed that if any observation had to be made on these two last-named papers they must be in the absence of the authors, as it seemed not at all likely they would be present. He thought, however, that they could not better employ their time that day than in reading the Appendix of Mr. Hall's paper, and in examining the Map of the Coal Field.

The SECRETARY then proceeded to read the Appendix, which occasionally in its details called forth some discussion, but it principally consisted of explanatory remarks relative to certain portions alluded to by the President, Mr. Potter, and other members, but more especially as to what was considered the deepest point of the Coal Field. After the Appendix was finished,

The PRESIDENT complimented Mr. Hall upon the usefulness of his work, and thought his suggestion regarding a model of the Coal Field well worth the consideration of the Institute. He, therefore, solicited the opinion of the Institute as to what could be done by way of accomplishing so desirable an object.

Some discussion then ensued, in which all who took part seemed to be favourable to the construction of a model; and finally, the following resolution was unanimously agreed to:—

"That the Council be requested to take into consideration the practicability of constructing a model, or plans and sections, illustrative of the Coal Field of this district, together with the scale upon which such model or plan ought to be constructed; and that the Council also take into their consideration Professor Owen's application for plans and sections, or specimens illustrating the Geology of the Northern Coal Field, for the Parisian Industrial Exhibition."

The PRESIDENT next referred to the further consideration of Mr. Greenwell's paper, and especially referred to the strata which crosses the overlap "faults" of the Coal Field of Radstock. This he considered

rather extraordinary, and to his mind the overlap appeared the effect of the dyke producing a lateral slide of the strata, so as to cause one portion to overlap the other.

After a brief discussion the subject dropped.

The PRESIDENT thought it necessary before they separated to refer to Messrs. White and Grant's Patent Safety Cages for Mines, a model of which they had then before them, and had also witnessed its mode of operation. For himself he thought the invention very simple, and likely to be useful to the trade. It was, therefore, proper that such an invention should be noticed by the Institute; and, as he then held in his hand the names of a few of the iron and coal masters of Scotland who had these cages in use, together with some statements relative to some accidents prevented by their use, he thought it desirable that they should be read to the meeting. The Secretary then read the following:—

Names of a few of the more prominent Iron and Coal Masters of Scotland, with the number of Patent Safety Cages they have in constant use in their Works.

	In use.	Orders to make.
William Dixon, Esq., Govan Iron Works	12	0
" " Calder Iron Works	15	0
" " Possell Colliery	8	0
Monkland Iron and Steel Company	20	6
Langloan Iron Company	14	14
John Wilson, Esq., Dundyvan, Kinniel, Lugar, and Muirkirk Iron Works	24	30
William Baird and Co., Gartsherrie	8	32
Carron Iron Co., Falkirk	18	12
Lochgelly Iron Company	10	0
Forth Iron Company	20	2
Combination of Airdrie Coal Masters	15	0
Archd. Russell, Wishaw Collieries	10	0
Lord Bellhaven	4	0
Duke of Buccleugh	3	0
Duke of Hamilton	8	0
John Horn, Esq.	6	0
	195	96

In short every coal master in Scotland has more or less of them.

Note of a few of the Accidents prevented by our Patent Safety Cages.

June, 1851.—At Stephenson Colliery, Holytown, four men from being overwound on a two-story double cage, the engine being beyond the control of the engineman, caused by the breakage of the tramp.

July, 1851.—Rope broke at Omoa Iron Works: cage arrested with its load. At this work there are sixteen in constant use, and there would have been frequent accidents, both from ropes breaking and overwinding, but happily prevented by their adoption.

July, 1851.—Barleith Colliery, Kilmarnock, cage and load prevented from being overwound. A similar accident occurred previously to getting our safety cages, when the damage done to the machinery cost upwards of £70.

Sept., 1851.—Five boys' lives would have been sacrificed by being overwound on a very high pit-frame, at Forth Iron Co.'s Works. The cage and its valuable load were safely arrested underneath the pit-head pulley. Also, one instance of a rope breaking with a man on the cage; and very numerous instances with loads of minerals.

Feb., 1852.—At Govan Iron Works, the rim of a pit-head pulley broke, the sudden jerk severed the wire rope, but the cage and its load were arrested 50 fathoms from the surface, with a load of two tons.

Feb., 1852.—At Carron Iron Co.'s Works, a cage overdrawn with one man on it: it was safely arrested underneath the pit head pulley.

Dec., 1852.—At Springhill Colliery, Baillieston, cage and load overdrawn: in consequence of the dense fog, the engineman did not see the mark on the rope.

Mr. Ainsworth, of Cleator, Cumberland, states, that in consequence of the short distance between platform and top of pit-head frame, the cages were frequently overwound and much damage done; but since the adoption of our safety cages, those kind of accidents have been entirely prevented.

May, 1852.—Mr. James Stuart, Omoa Iron Works, informs us that there have been nearly twenty instances where accidents would have occurred at their pits, both in overwinding and ropes breaking, which were effectually prevented by our safety cages.

June 2, 1852.—Two men overdrawn at Mr. Russell's pit, Wishaw but were safely arrested at the top of pit-head frame. Mr. Russell says that it is worth the price of twenty cages.

Oct. 8, 1852.—Mr. Dixon's Pit, Rutherglen. Accident prevented by overwinding: one man on the cage.

March 10, 1853.—Mr. Watts' Pit, Slamanan. Rope broke, two men on the cage; they were instantly arrested, having sustained no injury.

March 11, 1853.—At Mr. Robert Bell's Pit, Wishaw, one cage and man overwound; but being arrested, sustained no injury.

Sept. 14, 1853.—At Duke of Hamilton's Pit, Redding Colliery, a cage and one man overdrawn; sustained no injury.

Dec. 9, 1853.—At Kilmarnock, a boy on the top of hutch of coal was overwound; sustained no injury.

Many numerous other instances of more recent date could be given, but the above will give the idea of the kind of accidents usually occurring and prevented.

The meeting then separated.

NORTH OF ENGLAND INSTITUTE

OF

MINING ENGINEERS.

MONTHLY MEETING, THURSDAY, NOVEMBER 2, 1854, IN THE ROOMS OF THE INSTITUTE, WESTGATE STREET, NEWCASTLE-ON-TYNE.

NICHOLAS WOOD, ESQ., PRESIDENT OF THE INSTITUTE, IN THE CHAIR.

The minutes of the last meeting, together with the proceedings of the Council, having been read, the meeting proceeded with the election of the following gentlemen, who were declared to be duly elected members of the Institute:—Mr. John Walker, Wakefield; Mr. Richard Cordner, Crawleyside, Stanhope; Mr. John Trotter, Newnam, Gloucestershire.

Mr. REID next proceeded to read his paper "On Practice with Gas at Blowers."

ON PRACTICE

WITH

GAS AT BLOWERS.

BY MR. P. S. REID.

In introducing the subject which has been chosen as the title of this Paper, it will not be amiss to refer back, and take a retrospective glance at the history of that tremendously destructive power existing under the name of "Carburetted Hydrogen Gas," which is so well worthy of all our energies to endeavour to guard against its effects.

The first accurate views of the real nature of Carburetted Hydrogen are due to Dalton, some time about 1770 or 1780, and they have been followed up most instructively by Henry, Thompson, Davy, Faraday, &c.

The subject, however, of the normal condition in which gases are found in mines has sadly lacked investigation in a practical manner; so much has this been the case as to cause us to enquire how this is?

It appears to me to admit of a reply, and to some extent this may be a true one, that the genius of Davy when it invented the safety lamp, at the same time that he presented society with such a boon, gave us also an overweaning confidence in its efficacy, which caused us to relinquish enquiries as useless, when difficulties could be so easily combatted with so exquisite an invention, and that in many cases the gift has been accepted without due regard to its properties, and, in others, it has been thought that further investigation was unnecessary.

Our attention having been now pointedly directed to this matter by Mr. Taylor, let us hope it is only a beginning, and that many new facts will be contributed to so interesting a subject; let me, for my own part, anticipate that they will be more conclusive than what I am now going

to present you, which I regret to say is defective from several causes, the chief of which is, that it was not put into its present shape till long after the occurrences narrated, and with the lapse of time I need not repeat here, that memory becomes defective in many little points essential to accuracy.

With these remarks I proceed to say that in the Pelton Colliery, about 270 yards to the west of the present drawing shafts, there is a dip trouble which throws down the Hutton seam 10 fathoms to the westward, and brings down the low main seam, which at the shafts is 10 fathoms above it, exactly even at the point referred to; hence, in passing through the trouble we have the Hutton on one side and the low main on the other.

The course of this trouble is nearly north and south, and both to the north and south of the point at which the fault was found to have a downthrow of 10 fathoms; the main trouble diminishes in size in the first direction, at a distance of three-fourths of a mile to 4 fathoms, and in the other towards Waldridge Colliery, where it is known about a mile off to be a 6 fathom downthrow to the westward. Hence, it is evident that where the trouble has been cut is about the point of greatest depression of the strata, caused by the downthrow fault.

In the years 1845-6, it became necessary to explore the coal to the west of this trouble, with the view of supplying the colliery demand.

For this purpose, a drift was made in the direction as shewn on the annexed plan, and as the Hutton seam was known to have a natural rise of about 7 fathoms to the westward, in the 270 yards from the pits to where the trouble was proved, this drift was driven dead level, so as to cut out as much as possible of the downthrow, and so as (by continuing on) to take advantage of the natural rise of the seam west of the trouble, and cut it at the lowest possible level.

No brattice was used in this drift, but the airage during its prosecution was effected by staples, sunk as shown at the points A and B on the plan and section, that at A being sunk from the old Hutton seam waste, and that at B from the Low main seam, into which a place was driven of such size as to furnish a proper return air course (after the coal should be won) communicating with the Hutton seam waste, and thence to the upcast shaft, about half a mile to the north-east of the point B.

Whilst this drift was in progress several large feeders of gas were met with, mostly in the hard white whin stone post between the two stapples, which, as it was desirable to avoid the use of brattices, were conveyed into the returns by means of 2 bore holes, 3 inches in diameter, put down from the Hutton seam waste, which thus answered the double purpose of

a temporary return, and cleared the drift of the gas as fast as it accumulated.

By these means we arrived at the point C where, with the view of not spending too much money by driving in a very hard stone, it was determined to sink down upon the coal and ascertain its position, and it was found at a depth of three fathoms below the drift, with its regular rise to the westward, and we thus had encouragement to proceed to the westward with the expectation of cutting the coal at a distance of 144 yards, as indicated by the rise of the seam, which appeared here to be about 1½ inches to the yard.

As the stone at this place, however, was very hard, and we required coals very much, it was determined, in order to gain time, to incline downwards so as to cut the coal sooner, the drift was therefore drooped in the direction C D, as shewn by the dotted line, and the coal was cut at the point D.

Simultaneously with this, the staple B was sunk to E, so as to provide a return air course in the coal, in preference to driving one in stone, which would have occupied too much time, and we were encouraged to this by finding the seam tolerably dry at this place.

So soon as the coal was reached in the drift at D, a place was turned away both north and south, and after being driven 12 yards in the former, and 10 yards in the latter direction, was turned east, and thus driven until each were holed into the staple at E, and a communication thus effected with the chief return air courses, the southmost of these bords being driven under the main drift, and thus holed into the stapple.

With view of providing space for brattice, in case that should be required, the drift at C was widened out to 9 feet broad by 6 feet high, but previous to this it was only driven so as to furnish an area of 30 square feet, or 5 feet wide by 6 feet high.

Up to this time so little water had been met with in the progress of the work as to encourage hopes that these returns might be made available permanently for the ventilation, and thus avoid some very expensive stone excavating which might be needed to keep these air courses out of danger of being filled by water.

The returns, stapple, drift, &c., were, therefore, just finished, as described, about the beginning of April, 1847, when we again commenced working towards the westward, and at the point F we met with a rise hitch, lifting the seam 3 feet 6 inches to the westward, this was passed, and on the 22nd of April the place was advanced about 5 yards to the other side of it.

About 12 o'clock on this day, whilst the deputy was fixing a prop at this place, he observed an unusual movement of the thill and immediately afterwards an immense discharge of water took place, which filled up both returns, and in a very short space of time was flowing along the drift at the rate of not less than 600 gallons per minute. This discharge of water was accompanied by gas, but not at first to any serious extent so as even to fire at the deputy's candle, (which both he and the men had been allowed to use up to this time), yet there was sufficient to cause him to retreat, which he did forthwith, and in order to avoid any accumulation, he opened a manhole door at the stapple, so as to permit it at once to pass into the returns in the seam above.

Our arrangements being thus so completely and so suddenly foiled, we were compelled at once to adopt measures to pump the water, and orders were at once given to lay a set of pumps connected with the main engine, so as to effect this duty. Meanwhile an attempt was made to pipe the water, which failed, owing to the gas coming off so strong as to prevent any one breathing on the inner side of the point G, where the stone approached to 1 foot 6 inches from the surface of the water.

With the view, therefore, of shooting down the stone, a brattice was put in from the stapple edge so as to allow of 24 feet area behind it, and an attempt was made again, with no better success, to get under the brow at G, we, therefore, began to blast the stone down at this place. This was begun on the 23rd, at the same time it was evident that the water had diminished to half its former quantity, or 300 gallons per minute, but that as the water decreased the gas had increased, until it began literally to roar and cause a great commotion, lamps being obliged to be used, and the water boiling like a cauldron with the movement of the gas whilst passing through it.

We had no sooner commenced blasting the stone, when it became evident that we had no common blower to contend with, for at the fuse of the second shot on the 24th, it ignited, and continued after the charge went off to burn most furiously on the surface of the water with great noise, alternately coming out in a mass of flame, filling the drift on both sides of the brattice right out to about 2 yards beyond the stapple, and then returning under the brow of stone till nearly out of sight again.

We at first thought that it would extinguish itself by the motion of the water, which was very great, lashing up against the roof, but after waiting some time and finding it did not do so, and that the gas still continued to advance in a solid flame full 40 yards beyond the brow, and

being apprehensive that it might set fire to the coal or render the brattice useless, it was determined to try to knock it out with gunpowder. A favourable opportunity was therefore seized, when the gas had retreated under the stone, and a quantity of gunpowder (about 12 lbs.), was laid with a sufficient length of fuse to enable a man to get clear out of the way, which he had no sooner done than it exploded, and by its concussion extinguished the gas.

Our air at this time passing through the drift and round the brattice end, was quite equal to 10,000 feet per minute, and during the outbursts of flame alluded to, this was as effectually forced back as if a wall of masonry had been built across the drift near the stapple, and this at times would continue for the space of half a minute before it receded again towards the coal.

Whilst we were busy shooting down this stone, with the view of getting out of water mark, we were also preparing the lying set of pumps connected with the main engine, and it was also evident that the water had diminished to about 150 gallons per minute by the middle of May, when we were once more enabled to pump the water out and resume coal working.

From this time to the middle of August it was an incessant fight with the gas, which seemed, up to the middle of July, to regularly increase as the water diminished, evidently shewing that the one circumstance was contingent upon the other, as if following some law, no doubt, arising from their relative positions prior to the trouble being originally cut through.

After the middle of July the gas and water both diminished at this place, the latter to a mere trifling feeder of 10 or 20 gallons per minute, and the former so much so as to cause us no further trouble, save that required by the constant use of the safety lamp, for two or three months after that time.

Frequently during the period, however, up to the middle of July, we had immense outbursts of gas, far exceeding in quantity the one alluded to on the 24th of April, which was extinguished by the gunpowder. Before alluding, however, to them, I shall endeavour to shew at what pressure it issued on that day, so as to give an idea of how the gas increased in force as the water diminished.

On this occasion, we could not (as we afterwards did) get in to see the gullet, or fissure in the floor of the mine, from whence both gas and water were issuing; we could, however, observe it under the brow which was about

1 foot 6 inches from the surface of the water, passing to us with great force, and at the time of its greatest issue depressing the water in a wave of about 9 inches in depth. Assuming, however, that the water was quiescent, we had here an area of 12 feet square, under the brow from whence gas, coming out in an ignited state, forced back air which was passing along the drift at the rate of 10,000 feet per minute through an area of 30 square feet, and which, at the same time, must have been passing into the stapple, and no doubt flaming, some distance up in the return air.

As, however, we could not observe how far this occurred, we must content ourselves by saying, that the pressure of the gas passing through the 12 feet of area would, for the space of more than half a minute, be ballanced, or in a measure, placed in equilibrium with the force of the atmosphere at the 30 feet area of intake, and the 24 feet of return air course behind the brattice plus, the motive force, or manometric pressure of the air, flowing at the rate of 5½ feet per second, but, as the latter would only be about 2 or 3 lbs., we may neglect it in the present calculation.

As the point in question is about 120 feet below the level of the sea, it will be fair to take the atmospheric pressure in this instance at 15 lbs. on the square inch, adding, therefore, the areas of the intake and return, 24+30=54 square feet, or 7776 square inches, the atmospheric pressure upon which would be equal to 116,640lb., which adapted to the area of 12 feet, between the brow and the surface of the water, will give a ballancing force of 67½ lbs. or 4½ atmospheres upon each square inch of surface at this place.

Our gas, on this occasion, was ignited, but we had many proofs without the presence of the flame on several occasions about this time, that the blower was constantly yielding gas in the same, or even greater quantities, amongst the rest it frequently ignited at the blast or "shot," and was extinguished by the concussion and motion of the water, and on such occasions as we were compelled to use gunpowder it was only by watching an opportunity, and using the saltpetre paper, that we could succeed in blasting. It was also often impossible to keep the davy lamp burning, even close to the stapple, and if you advanced beyond a certain distance into it, say 4 or 5 yards, your lamp went out, and you were immediately affected with a strange swimming in the head, and on attempting to speak you were conscious of your doing so, but could not hear your own voice, if you still persevered, or remained standing, your next sensation was a trembling of the knees, and if you did not attend to this, giddiness ensued, and you

fell down insensible. I have frequently seen men brought ought in this condition, who on recovering their senses in the fresh air, were seized with vomiting and nausea which lasted several hours. *a*

Upon the 10th of May we were again enabled to get in to the coal, much of our stone having been blasted down, and our water all pumped out.

Owing to the proof we had had of the blower, it was determined no longer to rely upon air courses which might be filled up with water. Our air, therefore, was increased to 20,000 feet per minute, and men were set in to take the coal off, to the breadth of 10 yards in the north return, as shewn on the plan at H H, so as the stone could be blasted down to enable us to have a clear air course, out of the reach of the water, a stone wall also separated the stapple from the intake air, and in this wall a proper man-hole door was left, so as to have access to the pumps.

The eruptions of gas I have attempted to describe were very terrific in their appearance, and the noise which they made in passing through the water was similar to that of artillery, and had they continued permanently instead of by sudden outbursts we should have had no choice in advancing into the coal, but to have increased our air to such a quantity as to dilute the gas to an inexplosive point. Safety lamps were almost valueless, and I have frequently known every man working in the returns at K K obliged to retreat out in the dark to the flat, the only utility of his davy being to warn him of the fact, (which his own sensations told equally soon,) that he was working in an irrespirable atmosphere, and that if he did not retire asphyxia would be his fate.

It would be tedious to refer to each occasion when the gas was found to be most troublesome, I will therefore refer to one or two cases from which practical deductions can be drawn.

a Since writing the above description of sensations it has come to my knowledge that Signor Cardone, an Italian philosopher, published in the *Giornal di Fisica*, 1827, the results of some experiments upon the inspiration of inflammable gases, and as the sensations he describes coincide to some extent with our own, I subjoin them as follows, premising that experiments of this kind are so rare as to add to the interest produced by them:—In consequence of the difference of opinion respecting the effects of the inspiration of inflammable gas on the lungs, expressed by Scheele Fontana and others, the Italian philosopher, Cardone, lately instituted some experiments on the subject. The air being expelled from the lungs as much as possible, the mouth-piece of a bladder, containing thirty cubic inches of gas, was applied to the mouth, and the gas inhaled at two inspirations. An oppressive difficulty of respiration, and a distressing constriction at the mouth of the stomach were the first sensations. These were followed by abundant perspiration, a general tremor over the whole body, seeming to commence at the knees, an extraordinary sense of heat, slight nausea, and violent head-ache. "My eyes," says Signor Cardone, "beheld things indistinctly, and a deep murmuring sound was in my ears. After a short time all these effects ceased, except that of heat, which increased in an alarming manner, but ultimately, by the abundant use of cold drinks, I was restored to my original state of health."

On the 17th of May whilst we were taking off coal in the north return the deputy was at the flat above, which was about 50 yards from the stapple along the drift, the air having been in first-rate condition just before when he had visited the men, fully 20,000 feet per minute being passed through, and he had just sat down when he was surprised by one of the putters coming out without his light, and his first words were, so soon as he could speak, that "he would defy any white man to live in that place, and he would go back no more."

He had scarcely spoken before four of the men rushed out and told the overman, who by this time had arrived, that it was as much as ever they could do to get out and save themselves, and that their lights were out, and they believed there were more men in, as they had stumbled over some one in the dark, but dare not stop to pick him up.

The overman instantly stuffed his handkerchief into his mouth and went in with all haste, his lamp went out after he had proceeded about 10 yards from the stapple, and shortly after he felt a tub which some one was pushing on slowly in the opposite direction, taking hold of this he gradually backed out, and found, on getting to the flat, that it was a man of the name Kell who was pushing it, and that the reason why he was coming so slow was, that he had clutched a boy by the breeches, and was leaning against the tub for support as well as to help him to find his way out.

So soon as they got to the station means were taken to revive the boy who, as soon as he recovered his senses asked "if the pit had fired."

Kell's account of the matter was, "that he had filled his tub of coals "and was waiting of the putter at the place marked L, and that the air "was tolerably good in his place, thinking however that the putter was "long he went out to see what was the matter when he had no sooner "got into the north return than he found his breathing affected, hasten-"ing on he found the lamp flame getting dim and just at this time he "fell in with the boy who had fallen down insensible whilst putting his "tub out, he immediately seized him by the trousers and it was with "much difficulty he was able to haul him safely out."

He added that he felt the gas so soon as ever he came out into the rolley-way, coming down with a very strong current towards him.

It would appear from this that the gas had taken the return more rapidly than the working place where Kell was, and that his air was not (up to that time) sufficiently diluted to be dangerous, the other men who were working at the places above and below him were affected in their breathing and instantly they felt this they retired.

The gas on this occasion had not to pass through water but came out of an open gullet in the floor of the mine, the area of which we could readily see when it abated to be about 1½ inches wide by 10 feet long crossing the whole breadth of the place or narrow bord.

We were also certain that the air was forced back to the stapple and that the returns, besides being quite full both on the south and north side were pouring their contents as fast as possible up the stapple towards the low main.

Taking, therefore, all these circumstances into consideration we cannot doubt that the pressure upon the area of this gullet which only equalled 180 square inches was equivalent to the atmospheric pressure at the stapple added to the pressure in the intake air course with probably the manometric pressure due to 20,000 feet of air per minute passing through it.

The manometric pressure being only about 7 lbs upon the area of 36 feet (which was the size of the intake upon this occasion), I do not think it worth taking into account, especially as it would be balanced by a corresponding pressure in favour of the gas on the other side of the stopping.

The area of the intake was, therefore, 36 square feet, and the area of stapple equal to 40 square feet, hence the atmospheric pressure would be equal to 164, 160 lbs.

Applying this pressure to an area at the gullet of the trouble equal to 180 square inches, we have the enormous pressure at the time the gas was issuing, of 912 lbs on the square inch, or equal to 60·8 atmospheres.

It seems almost incredible, on looking back to it, that we could have so great a pressure, but it must be borne in mind that this seldom continued for many minutes, whilst, at the same time, it must be remembered that not only the air was pressed back in the drift, but likewise that every possible place in the workings was filled up, whilst the gas was also flowing up the stapple into the return; we cannot, therefore, doubt that great as this pressure was, there is reason to think that for some seconds, and even minutes, it was still stronger.

Two points are required to be borne in mind with regard to the rapidity with which the two returns, and the intake or drift air-course were filled with gas on this occasion, both of which go far to establish the assumed conditions of equilibrio which I incline to prove. The first is the amazingly sudden way in which the whole area excavated was filled with gas. To use the words of the deputy, "He had," (after going his rounds and finding all right,) "just turned his back upon the men, and sat down at the flat, when it was announced to him that every place was full of gas, and it was with difficulty the first men got out."

The second is the apparent anomaly of Kell, at the place L, not being so soon affected to a suffocating extent as the other men, although even he could not be many seconds after they left before his attention was aroused, as he described it, by the sudden silence of the pit after the putter ceased to move.

This may be accounted for by the fact of the gas having pressed the good air more upon Kell than the other men; and although the process of diffusion would be undoubtedly going on, still the time was too short to admit of this being hurtful to a serious extent.

Again, with regard to the area of space filled *in, at the utmost,* a minute of time, the cubic contents of the several air ways would be as follows:—

The North return	14·139	cubic feet.
The Intake Air-course	16·240	„
The South return	10·665	„
The Stapple	2·600	„
Low Main returns	3·600	„
Total	47·044	„

Applying this quantity to the gullet area of the blower, and assuming the time of its exuding at one minute, we have the apparent velocity of gas escaping per square inch of surface in that time equal to 261·35 feet, or at the amazing rate of 37,634·40 per square foot of area.

Nor is this all, for it cannot be doubted that when the gas arrived at the point E, its density must have so far changed as to bring a fresh element into play; and its velocity in flowing up the stapple would be accelerated in the ratio of the specific gravity of the atmosphere and gas at this place.

By this cause its flow along the drift would be checked, and from it we may assume the reason of its ceasing to flow beyond a certain point, but remaining stationary at this place—thus causing us to conjecture that not only was the air current stopped back, but that the gas was flowing up the stapple, yet not with sufficient velocity, or even with the same rapidity as it was produced by the blower.

It will from these facts be seen, that in assuming a condition of equilibrio, we are under rather than above what the actual conditions of the case would justify.

I have assumed in this that the gas was merely forcing back the intake air, and not mixing with it; such, however, was not the case, as the explosion referred to on the 15th June would lead us to infer that the process of diffusion was in rapid progress.

Another and curious feature about this blower was the great degree of coldness of the gas and water at the point of issue, and even all the way as far as the stapple.

I am unable now to speak to the temperature in exact terms, our attention (being too completely concentrated upon measures of safety at the time) causing us to neglect an examination upon this point; beyond, therefore, the fact that the men complained bitterly of the cold whilst working in the water even at midsummer, and that in approaching the blower when giving out gas furiously, you felt as if a blast of excessively cold wind was coming against you, we can add nothing positive with regard to the temperature of the blower itself.

Had I been aware at the time of the importance of every detail, this part of our practice would certainly not have been neglected, as from what I shall hereafter refer to, I should conceive the actual temperature of gas, in its primary issue from the blower, will eventually prove to be an index of normal tension or pressure.

The actual pressures previously referred to are as close an approximation as we could come with the details in our possession, and to use the words of the workmen whilst the gas was at the worst, and we were passing all the air we could into it. "it was the same as pressing it against a stone wall, you couldn't lift her."

We were so fortunate in all the trouble we had with the blower, (which lasted several months, and though it ignited several times and exploded once,) as to pass through our ordeal without even a singed hair to any of our workmen.

The occasion on which it exploded was a curious one, and occurred on the 15th of June.

Six men had been busy shooting down stone, to increase still further the intake between the stapple and the blower, and had retired to get some bait or refreshment, to the outside of the stapple, and in order to show a better light one of them had stuck his candle against the wall at N, about four feet from the ground, whilst sitting here one of them happened to look up when he observed the flame suddenly lengthen, and immediately cried out to his companions that they were all lost, and had scarcely spoken when the gas exploded; they had started all up at the same time and were running along the drift as fast as they could, whilst so engaged the force of the explosion passed over them tumbling them all head over heels, but not burning any of them.

When they got to the turn at the shaft end of the drift they then looked back and saw the gas quietly go out of itself.

An examination of the drift afterwards showed us that the stopping at the stapple had been blown down from the intake side, and that a stone stopping at the top of the arch at M, had been shifted from its place all in a lump, although built very strong and 7 feet thick.

The remarkable escape of these men can only be accounted for in this way, that the gas had tailed out as shewn in the annexed plan, and that although the extremity of the tail would be meeting the air and gradually becoming more explosive, yet, that none of it was *eminently so*, and that though the blast had had sufficient force to knock out the stapple stopping, yet as soon as it got to the west of this point it merely ignited the gas and then extinguished itself.

As there were no signs of burns about any of the men, we may come to the conclusion that their being turned over and over, as described, was due merely to the motion of the air caused by the explosion, and that this was also sufficient to move the wall at the point M, which, as before said, was 7 feet thick. It cannot at the same time be doubted that had our current of air been less energetic the diffusion would have been greater, the explosion would have proportionably increased in violence, and that its effects would have been far more serious.

We had also another practical proof of the force of gas coming from this blower at another time, which is worthy of remark.

In order to avoid pumping the water still exuding from the gullet or fissure at the trouble, it was advisable to try and dam back a portion of it so as to raise its level, and thus get it to flow through pipes to the level portion of the drift, and thence to our engine pit.

In doing this, we attempted, in the first instance, to put it (the dam) in close to the trouble because we were rather confined in distance of coal to make the work secure.

Our first essay proved a failure, from a most unexpected cause, as we had, without knowing it, planted the dam upon a fissure in the stone, from whence it was apparent both gas and water was issuing alternately. Our dam was constructed of Memel balks cut in two, and placed one above the other, clay being beaten in on the inside, so as to make all tight as we proceeded. The timber was cut 10 feet long, so as to have a hold on each side, as shewn in the annexed diagram, and we got five pieces in as shewn, and then began to put in props of larch 9 inches diameter, two of which we succeeded in getting in, and had nearly gotten in the third when the pressure from below raised the dam so as to force and literally split up our props against the roof, like so much matchwood, completely into shivers, we were thus obliged to shift the position of the

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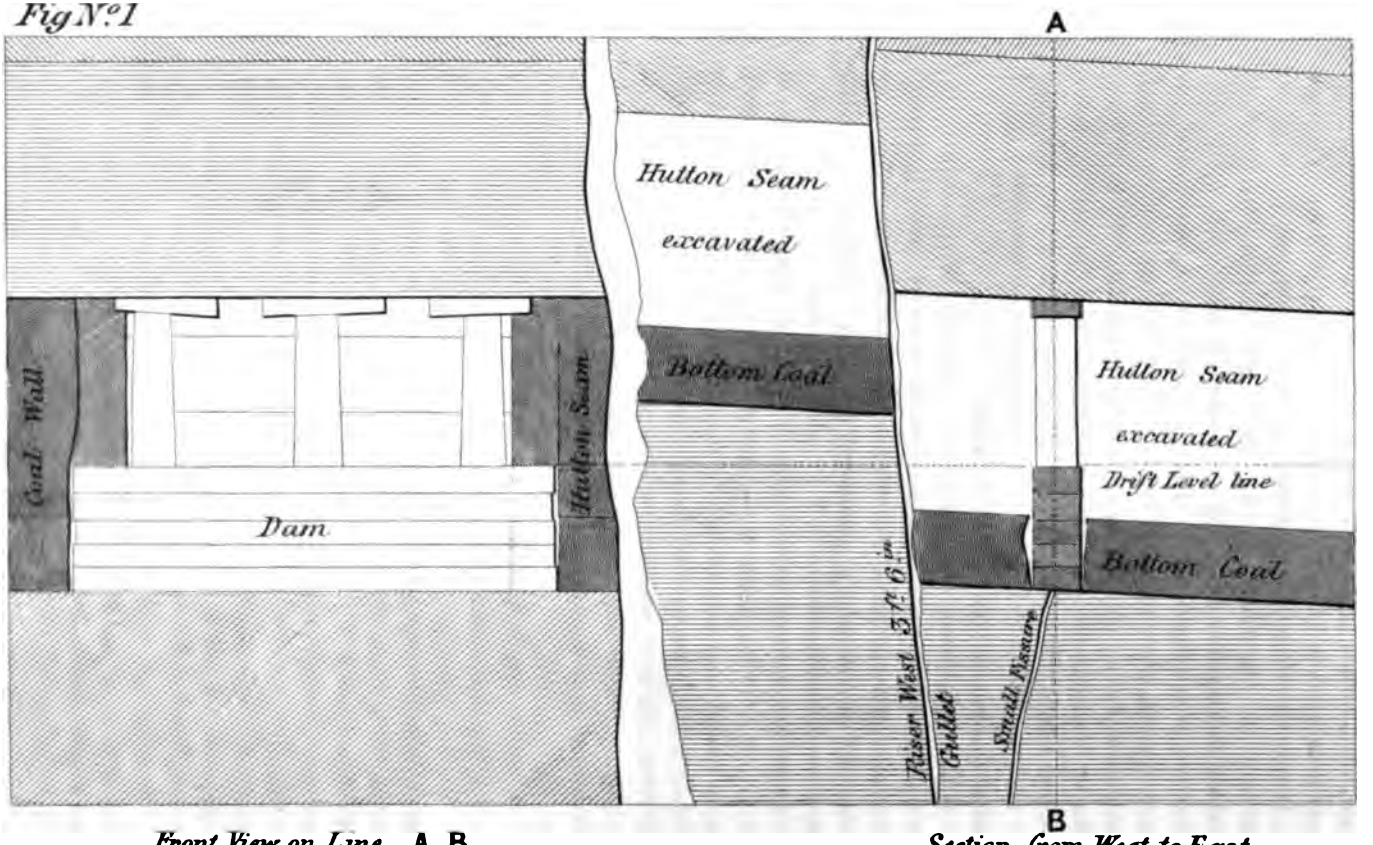
Fig N°1



Front View on Line A. B.

Section from West to East.

Engraved by Pilgrim St Newcastle.

dam, 2 feet further eastward, where we succeeded in getting it in with very little trouble.

During the whole time, however, we had conclusive evidence of the purity of the gas, which frequently forced us to retire for fresh air above, and no lamp could be got to live more than 5 minutes in it unless constantly kept moving, the effect of the gas when in its purest state, was most injurious to the men, not one of whom could remain more than 5 minutes in it at a time when it was at its greatest pressure without becoming insensible, or on getting out into the fresh air being excessively sick, as I have before described, and in addition to this if he continued in for 2 or 3 days occasionally working amongst it, it was several weeks before he recovered his health and colour.

Having now detailed our practice with this blower during the 4 months in which so much trouble and anxiety was experienced with it, I must now proceed to such theoretical and practical deductions as this exceedingly important subject deserves, and which doubtless will be interesting to the members of the Institute.

In doing so I would wish to divide the subject into three heads, the first being as to the origin of the gases we meet with in coal mines, both in the coal itself and in the circumstance of blowers, as in the case of Pelton in 1847, the second referring to such suggestions as have struck me with regard to contending with inflammable gases in this shape, and thirdly, with reference to such future steps as may appear necessary to follow out and investigate more fully than heretofore this important subject.

1st.—Origin of Gases in Coal Mines.

It appears to me that there are only three positions in which gas can be simply produced in coal mines. I say simply produced, because I would submit, that in the case of such blowers as have been described at Pelton, the gas has not only been produced but stored in a very remarkable manner, to which I shall hereafter refer, distinguishing it however from such freshly formed gas as is commonly met with in the coal itself.

The three positions referred to are as follows, firstly, by mechanical compression upon seams of coal; secondly, by subterranean heat acting upon the coal; and thirdly, by the decomposition of animal, vegetable, or mineral substances, as in the case of pyrites.

With respect to the third position, it does not appear to me that it can come into action in coal mines except in the case of decomposed pyrites, and even in this case it is not the sort of gas which is generally met with,

and that the instances of sulphuretted hydrogen have not been sufficiently proved in coal mines to demand more than a passing remark that it ought not to be lost sight of in future investigations.

Again, with regard to subterranean heat, we have no proof that its action on the seams hitherto reached, are sufficient to produce gas, whilst, on the other side, we have abundance of proof that it is not the deepest seams which are most prolific in gas, hence, until more conclusive proof be had, we must reject the theory that gas is evolved in coal mines by the agency of subterranean heat.

We find, for instance, that the Monkwearmouth pit, which is far the deepest of our district, with the single exception of the new Seaton winnings, enjoys an almost complete immunity from gas comparatively, with many mines of one-third the depth, and in none of the authenticated cases of casual or permanent issues of gas do we find temperature at all alluded to as forming an item deserving attention, of course I speak of coal mines, with regard to issues of gas on the surface of the earth, there are numerous cases, such as in the Caspian Sea, &c. &c., and chiefly in the neighbourhood of hot springs, whose temperature no doubt will have some connection with these issues of gas. *b*

Next with regard to issues of gas by mechanical compression it would appear from all the evidence hitherto brought forward that this must depend upon two circumstances, firstly the natural structure of the coal and the power or force employed, or in other words upon the weight of strata bearing upon the coal in its natural state in the mine.

In proof of this I would refer to the Hutton seam which is known at Bedlington as a hard steam coal, and is *there* almost devoid of issue of gas, whilst the same seam at Wallsend, Felling, Hebburn, and in the Wear (but with an entire change in its natural structure,) is notorious for its production of gas, so much so as even to light up in the tubs, in which fractured pieces are being brought to bank so soon as you lift a few pieces and thrust a candle into them.

Sir Humphrey Davy who I believe has done more than any other man since the commencement of the present century to inform us of the true nature of explosive gases, plainly points out that gas is very simply evolved from coal by mechanical pressure, and with view of proving it he

b The chief places where carburetted hydrogen gas is known to exude on the surface of the earth, in which the cause is traceable to the operations of heat, are at Pietra Mala in the Tuscan Appenines, Iceland, Pont Gibaud in the Auvergne, and on the west coast of the Caspian Sea—all more or less the loci of volcanic influences.

bruised some large lumps under water, and they gave off inflammable gas. *c*

If then, fire damp or gas can be forced out of isolated fragments of coal simply by bruising them it is not difficult to see what must be the effect of enormous weights of strata pressing upon coal in the natural bed especially when further increased by the excavation of large tracts of pillars and workings.

Supposing that there was no issue from blowers in the barred-up mine, the case of Percy Main (so accurately described by Mr. Taylor) establishes the fact that *there* the natural issue from that seam is at a pressure of 4½ atmospheres, yet there are cases where the same seam is almost free from gas even with the same cover as at Percy Main, hence this issue must depend upon two causes, viz., *the cover* and the natural or chemico-mechanical structure of the coal.

A comparison therefore of all the circumstances connected with cases of this kind is therefore needed to come to a true conclusion, and I do not doubt that were such rigidly instituted it will be found that in proportion to the specific gravity and the several predominant chemical constituents so will be the pressure at which the gases will issue from the coal in its natural bed.

Probably a microscopical examination may at some future time lead us to compare different coals together, or even to measure the minute pores from which the gases issue, if this could be done a further verification of this theory might be found.

Again, with regard to blowers, they occur under such different phases it is difficult to come to an accurate conclusion, with some the gas comes off dry, and there is a total absence of water, whilst in others it comes off with water, and it cannot be doubted its issue is intimately connected with this element, in others again the blower lasts for a few days or months, and frequently it has been known to endure for several years.

With regard to the Pelton blower of 1847 it ceased very soon after the

c The fire-damp is produced in small quantities in coal mines during the common process of working. The Rev. Mr. Hodgson informed me, that on pounding some common Newcastle coal fresh from the mine, in a cask furnished with a small aperture, the gas from the aperture was inflammable; and on breaking some large lumps of coal under water, I ascertained that they gave off inflammable gas. Gas is likewise disengaged from bituminous schist when it is worked. This is probably owing to the coal strata having been formed under a pressure greater than that of the atmosphere, so that they give off elastic fluid when they are exposed to the free atmosphere; and probably, coals, containing animal remains, evolve not only the fire-damp, but likewise azote and carbonic acid, as in the instance of the gas sent by Dr. Clanny.—Page 23, *Sir H. Davy on the Safety Lamp, and Researches on Flame.*

final diminution of water, and my own view of its existence is based upon one of two positions which I shall describe by aid of a diagram.

One peculiar feature of this blower was, that both it and the water came from the floor of the mine apparently from a lower level, and we find wherever we have attempted in this mine to go deeper than the Hutton seam, we have met with gas accompanied with large feeders of water, in one instance where I bored 200 feet lower we had a large quantity of water and gas mixed, and from this point the gas has never ceased, although it is now 5 years since the hole was put down.

My view of the Pelton blower is this: the 10 fathom trouble referred to so frequently, is a great derangement of strata passing from Farnacres over by Pelton and so southward over a great extent of country, in this wide range there must be many crevices or fissures connected with the main trouble, all acting as service pipes from some head of water, probably at a very great distance, and that until the moment of cutting the feeder on the 22nd of April, this column of water had held back the gas in a highly compressed state, and that so soon as it was relieved of this pressure, it issued into the mine at the same or even a greater pressure than that of the water itself, thus:—*(See Diagram.)*

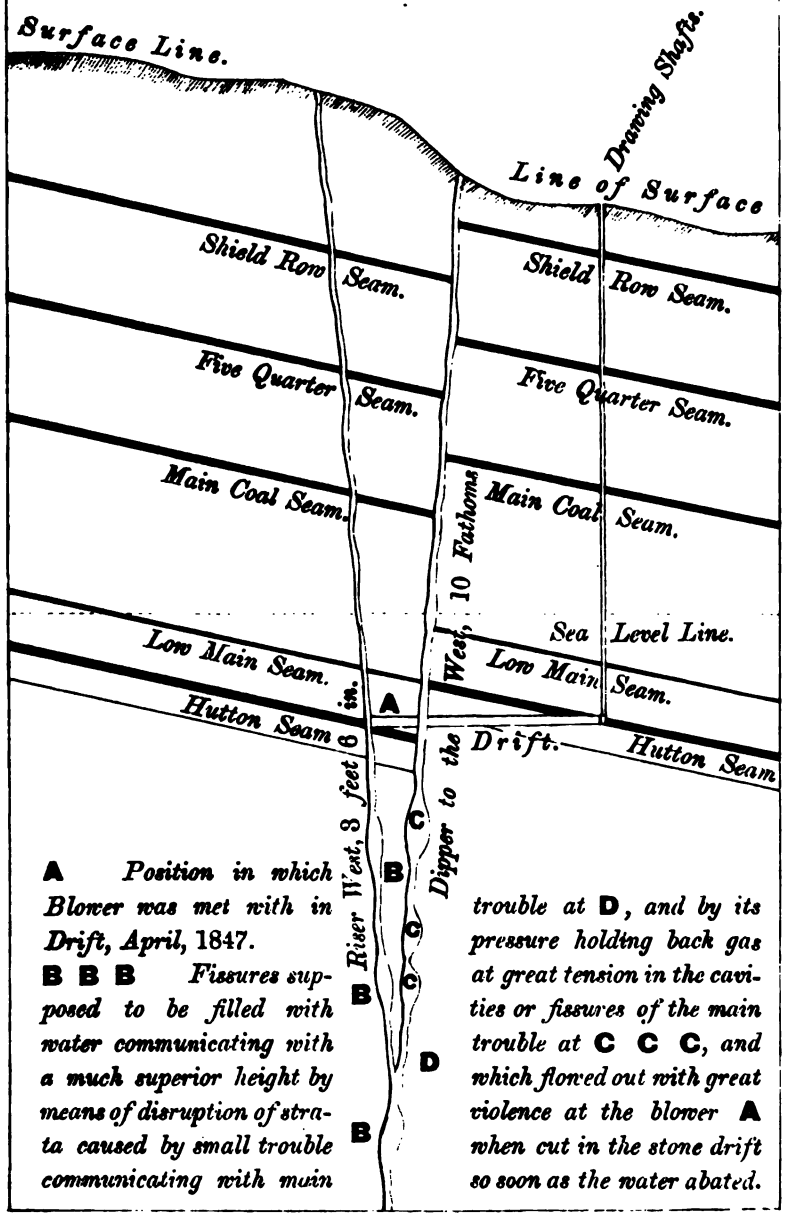
The question is where have we the height of ground necessary to give so great a pressure as 912lbs. on the square inch, or 60 atmospheres, to this I reply that the highest hill of the coal formation in the County of Durham is probably about 15 or 1600 feet above the level of the sea, suppose we take it at the latter, we must add 120 feet for our position below the sea, this gives us 1720 feet as the probable height of water column in the case of Pelton.

Simply assuming 35 feet as the quantity necessary to balance an atmosphere, we have 1720÷35, or 49·14 atmospheres, which taken from 60·8 leaves 11·68 atmospheres still wanting to complete the pressure.

This would, therefore, appear contradictory, but if it is recollected that the gas and water both came from the floor of the mine, and that there is no knowing how far these fissures may proceed downwards, we shall still conclude that there is probability enough left in this conclusion.

Secondly, we have also the fact that large masses of strata when separated for a length of time by so incompressible an agent as water, may, by being relieved of it, suddenly collapse, and thus go far to explain the pressure of gas and the intermittent character of the blower I have attempted to describe.

Sketch to Illustrate supposed Relative Positions of Water and Gas at Blower in Pelton Colliery, in Drift of 1847.



A *Position in which Blower was met with in Drift, April,* 1847.

B B B *Fissures supposed to be filled with water communicating with a much superior height by means of disruption of strata caused by small trouble communicating with main trouble at* **D**, *and by its pressure holding back gas at great tension in the cavities or fissures of the main trouble at* **C C C**, *and which flowed out with great violence at the blower* **A** *when cut in the stone drift so soon as the water abated.*

2NDLY.—SUGGESTIONS FOR FUTURE CONTENTION WITH BLOWERS.

There are several points which have been forced upon me by the struggle we had with the blower of 1847, and which will be applicable to similar cases.

In the first place, I would submit that mechanical or steam jet, or in fact, any ventilation which, unlike the furnace would have ceased on the first cessation of the prime mover by the fracture of machinery pipes, &c., and whose momentum would end almost simultaneously with that fracture, would be most imprudent in a case like the Pelton blower.

What, I would ask, would have been the result (if we had adopted mechanical ventilation) on any of the great occasions of eruption I have referred to? why instead of the gas coming so far out and reversing our air currents it would have mixed and diluted our channels all the way to the surface, where it would have been very difficult to have prevented its contact with flame, and who, in such a case as this, could venture to predict the frightful results with certainty?

The fact is that the underground furnace is peculiarly adapted for coal mines, and for blowers of this sort in particular. It possesses a permenancy of action in the heated shaft which endures long after the fire itself is extinguished, which is possessed by no other system of ventilating power.

Although in the case of Pelton *this could not be done* but with regard to future blowers, I should strongly advise all exploring places to be pushed far in advance, where hitches are expected, and having found the benefit would recommend the returns to have at least three times the area of the intake, so as in case of sudden eruption there might be a space of at least three times the content to be filled before any backing of the main air current could occur. The intake should also be enlarged as much as possible.

Lastly, it will be seen how progressively the air current was increased as the gas got stronger in our case, and how, notwithstanding all this, the the lamps were useless amongst gas of so dense a nature; so much was this the case as to cause me seriously to enquire *whether or not* provided the area of my air currents could be still further increased, it would not be more prudent to increase their area together with the returns, and use nothing but naked candles, relying upon the non-explosive nature of the gas in its pure state, in preference to leaning too confidently upon the use of lamps, which I feel sure has been frequently done to a dangerous and improper extent.

3RDLY.—FUTURE INVESTIGATIONS.

I should after all I have seen be inclined to consider it by no means

[illegible]

NORTH OF ENGLAND INSTITUTE

OF

MINING ENGINEERS.

MONTHLY MEETING, THURSDAY, DECEMBER 7th, 1854, IN THE ROOMS OF THE INSTITUTE, NEVILLE HALL, NEWCASTLE-UPON-TYNE.

NICHOLAS WOOD, ESQ., PRESIDENT OF THE INSTITUTE, IN THE CHAIR.

The PRESIDENT called upon the Secretary to read the minutes of the last meeting, and also of the Council. These having been read,—

The PRESIDENT said the members for election to-day, were—Mr. Thomas Wales, of Dowlais Iron Works, near Merthyr Tydvil, proposed by Mr. Edward Sinclair and himself; Mr. Samuel Hunter, of Tredegar Iron Works, near Newport, Monmouthshire, proposed by Mr. Edward Sinclair and himself; and Mr. John Trevor Barkley, at present resident at Constantinople, proposed by Mr. Edward Potter and Mr. H. G. Longridge.

These three gentlemen were, respectively, elected unanimously.

The PRESIDENT observed that previously to the reading of Mr. Longridge's paper, he believed the first thing, according to their regular routine of proceedings, would be to enter upon a discussion of Mr. Reid's paper. But as gentlemen had only had that paper in their hands a day or two (some, probably, not having yet received it at all,) it would be, perhaps, more convenient, if it met with the approbation of those present, to postpone the discussion till next meeting.

This arrangement was unanimously assented to.

Mr. T. Y. HALL intimated his intention to nominate Dr. Richardson as a member of the society.

A letter was read from Mr. J. Dumolo, of Dunton House, near Coleshill, Warwickshire, requesting the Secretary to give notice of his intention to nominate Mr. James Holt, of the Stanton Iron Works, near Derby, as a member of the Institute.

Mr. LONGRIDGE then read his paper on "The Coal Fields of the Ottoman Empire."

In the course of the reading, and subsequently, some questions were asked by members with respect to its statements.

Mr. T. J. TAYLOR remarked, that the coal field which had been thus described was much larger than he had had any idea of.

In reply to the President, Mr. LONGRIDGE remarked that the limestone was found underlying the grit; and, in reply to another member, he said that in the district described, hills were thrown up in every direction and in every form. The whole district was extremely mountainous. In answer to another question, Mr. Longridge said that the spontaneous combustion referred to in the paper arose from pyrites, and not from the coal.

Some specimens of coal from the district described in the paper were produced by Mr. Longridge, and examined by several members.

Mr. LONGRIDGE remarked that the Rodosto coal was perfectly cubical, but there was a difference in fracture between that and the Selivrea coal.

Mr. DUNN observed that the specimen from Selivrea was like a kind of fossil coal; it looked very like the parrot coal of Scotland.

In reply to Mr T. Y. Hall, Mr. LONGRIDGE remarked that it burnt to a red ash.

Mr. HALL spoke of coal in certain districts in Austria which was very like it; it produced very little flame, and burnt away entirely to ash.

The PRESIDENT suggested that Dr. Richardson should be requested to analyse the specimens, and that the result of his analysis should be printed to accompany the paper.

It was understood that this was agreed to; Mr. LONGRIDGE remarking that the specimens he produced were perfectly at the service of the Institute.

[Accompanying the paper, it may be here remarked, was the result of an analysis of several specimens by Dr. Lyon Playfair; which had been forwarded for that purpose by Mr. Longridge. There were also appended reports from the Admiralty as to the value of the coal for the purposes of war steamers.]

Mr. LONGRIDGE observed that he did not produce these pieces of coal as samples of the coal generally in the district. The Rodosto coal burnt much brighter than the Selivrea coal.

In answer to Mr. Taylor, Mr. LONGRIDGE remarked that the Erekli coal differed altogether from a bituminous coal; it burned quite bright, like Newcastle coal; in fact, it was very little different from the Newcastle coal.

Mr. TAYLOR asked if there was anything of which Mr. Longridge was aware, that would cause a bituminous coal to assume that shape.—Mr. LONGRIDGE said: Nothing whatever.

The PRESIDENT thought it was a sort of anthracite coal.

In reply to Mr. Hall, Mr. LONGRIDGE remarked, that in some instances the coal beds dipped down towards and underneath the sea.

The PRESIDENT suggested, that Mr. Longridge should prepare a sketch of the localities to which he had alluded in his paper; giving a larger sort of outline than could be obtained in an ordinary map. This would form a very desirable accompaniment to the paper when printed. They were very much obliged to Mr. Longridge for giving them a description of this coal field; which to him (the President) was very much more extensive than he had had any idea of.

Mr. LONGRIDGE assented, and promised to prepare such a sketch as the chairman had suggested.

The PRESIDENT said, their next proceeding was with reference to a paper with which they had been favoured by Mr. Atkinson. It was very voluminous, and he thought it would prove to be a very valuable paper. It contained, however, so much of analysis that it was scarcely suitable for reading at a meeting like the present. The Council had examined it; and they thought it had better be considered as read, and printed in the proceedings of the Institute: the Society could then come to its discussion at the next meeting. The President read the various headings of the paper; which is devoted to the subject of "The Theory of Ventilation." It seemed (he said) to comprehend everything relating to the ventilation of mines; and Mr. Atkinson must have taken a great deal of pains in the production of such a paper.

Mr. T. J. TAYLOR remarked, that the paper was valuable as a sort of compiled history of what had been done up to the present time in connection with the subject of ventilation.

Mr. DUNN asked, if the paper could be abbreviated.

The PRESIDENT said: Not beneficially. The subject was a very complicated one, branching out into different sections; and the paper brought their information down to the present time.

It was understood that the paper would be printed and circulated in the proceedings of the Institute, and discussed at the following meeting.

A Member suggested that as the paper was so voluminous, it should be divided into four or five papers; which would admit of a more ample discussion.

The PRESIDENT thought it would be better to have it printed altogether; and then it might be discussed at as many meetings as might be found necessary.

Mr. ATKINSON concurred in the Chairman's suggestion; because one chapter was so linked in connection with the others, that each would be incomplete without the remainder being printed.

From some conversation it was understood that Mr. T. Y. Hall would contribute a paper on certain coal fields which he had visited in Austria; and the President suggested (as he had done with reference to Mr. Longridge's paper) that Mr. Hall should lay before them at the same time a sketch of the locality.

Mr. DUNN feared that the Institute too seldom got its papers thoroughly discussed. Mr. Hall's last paper had never been thoroughly discussed; it had only been touched upon.

Mr. TAYLOR would be glad to see the printing of the papers completed earlier. If the papers were in the hands of members a week before the meeting, that would be satisfactory. But this was never the case. He (Mr. T.) did not get his copy of Mr. Reid's paper till yesterday.

The CHAIRMAN threw out the suggestion of allowing a month to intervene after members received the papers before discussing them.

Mr. DUNN feared the interest would be lost by the intervention of other topics. He thought, with Mr. Taylor, that it would be desirable if the printing could be forwarded.

The PRESIDENT said, every effort had been tried to accomplish this, but it had been found impracticable to obtain greater dispatch than at present. The President suggested that if it were thought Mr. Hall's paper had not been completely discussed, the discussion could be again gone into.

The PRESIDENT said, the next subject to which he had to direct attention was one of very great importance, as the members would have observed by the circular. It was the question of establishing a Mining College, connected with this Institute. The Council had sent a few heads of what was generally proposed to be the outline of such a college. These had been only hastily drawn up, not under any expectation that they could be regarded as perfect, but rather as heads for discussion at a meeting of the members. The Council had considered the subject very

seriously, and discussed it at very great length; and they had come to the unanimous conclusion that the best plan would be for the members to appoint a committee—or to appoint the Council themselves to act as such committee—to draw out the details connected with the proposed college more specifically than was done in the paper before him. Such a committee would state every thing relative to the college in detail, and more specifically than was pointed out here. If this meeting thought such would be a proper course, it would render it unnecessary to go into a discussion of the different points to-day. It was proposed that a special meeting should be called, at which the report of such committee (or of the Council, if appointed) should be laid before the members, and then its discussion could be entered upon. Perhaps it would save time if such a course were now adopted. At the same time he should be very glad to hear any observations which any gentleman had to make upon the subject, because that might assist the Council in drawing out the details. The President added that time was especially an object in this matter, because there had been many applications and inquiries as to what progress had been made towards the new institution. During a journey into some of the other mining districts, last week, several persons had been inquiring when they could send their sons here; therefore time was of some consequence. According to regular routine, there would be no meeting of members next month, being the Christmas season; there would be no regular meeting till two months hence. That would be too long a time to defer the subject, which should be decided upon as soon as possible. If the meeting should think it advisable to pursue such a course as he had pointed out, it would be necessary for the Council to meet this day fortnight.

Mr. Dunn (to the President): Do you mean that the Council or committee should report upon each of the heads laid down in this paper?

The President: Yes.

Mr. T. J. Taylor: Or in any way they may think fit to deal with the subject—to report at large.

The President: To consider what is necessary for the mining population and for the mining engineers. If a Mining College were established here, no doubt those connected with our chemical manufactories, and, in fact, all connected with the manufacturing interests of this and other districts would send their sons, because it would be adapted to them as well as to the mining population. But the great object would be to meet the wants of the mining interest; and it would be for the Council,

or the committee whom you may appoint, to adapt the institution as much as possible for that purpose—still keeping in mind that it ought to be *generally* useful, or it will not be successful.

Some conversation then followed, in which the President suggested whether it would not be desirable that whatever report was drawn up should be circulated among the members previously to the meeting for discussion, so that they might come prepared for such discussion.

Mr. Dunn suggested whether it might not be desirable to encourage members to send in suggestions to the Council previously to their drawing up their report.

Both these suggestions appeared to meet with general concurrence; and the conversation terminated in the unanimous adoption by the meeting of the following resulution :—

"That the Council shall be instructed to draw up a plan, in detail, for the institution of a Mining College—giving the scheme or system of education to be pursued; the terms of admission; the support to be sought for such institution, with all other requisite details; and that this report be laid before a special general meeting of the members of this society, to be convened for that purpose on this day month, the 4th January, 1855.

"That, in the meantime, the Council will be glad to receive from individual members any suggestions that may be deemed useful, the same to be sent in on or before the 16th instant; and that these resolutions be conveyed to the members by circular forthwith."

A Member asked if the report of the Council would be circulated at least a week before the meeting?

The President said: At least a week, if it could be accomplished.

Mr. T. J. Taylor then directed attention to the following letter, which, he said, had been received from Professor Airey by Mr. Anderson :—

"Royal Observatory, Greenwich, Nov. 29, 1854.

"Dear, Sir,—It will, I am sure, be satisfactory to you to know that upon working up our pendulum experiments we have this day come to a set of results, which enables me to say that the instruments have stood perfectly well, and that there is every hope that the conclusion will be in the highest degree trustworthy. The result now obtained is that the force of gravity is greater at the bottom of the mine than at the top by $\frac{1}{1990}$ part, or that a clock which goes true time at the top would gain $2\frac{1}{4}$ seconds per day at the bottom; and this implies that the general density of the earth is 2·7 that of the coal measures; which is a greater den-

sity than I expected. I am now encouraged to go on working up every part of the problem with greater care. And I write this day to Mr. Arkley, begging him to give me a small piece of information which will guide me in making preparations for the next step, namely, the accurate measure of the depth of the mine.

"I am, my dear, sir,

"very truly yours,

"G. B. AIREY."

Mr. TAYLOR remarked, that the experiment was a very curious one, and gave results much higher than had been obtained by other experiments; especially by the Cavendish experiments, and those on the mountain Schiehallion. Mr. Taylor said that on a rough calculation, he conceived the medium density of the coal measures to be 2236; water being 1000. Now multiplying this result by 2·7, it gave the mean density of the earth at 6·3 times that of water; which was larger than they had hitherto been taught to expect. The nucleus of the earth must therefore be very heavy.

The PRESIDENT observed, that some experiments of a similar character in Cornwall, had failed very much in consequence of the difficulty of getting correct measurement of depths, and good communications underground. But in the present instance, the experiments had been much more accurately conducted; and there was reason to be very sanguine that some very accurate conclusions would result.

The meeting then separated.

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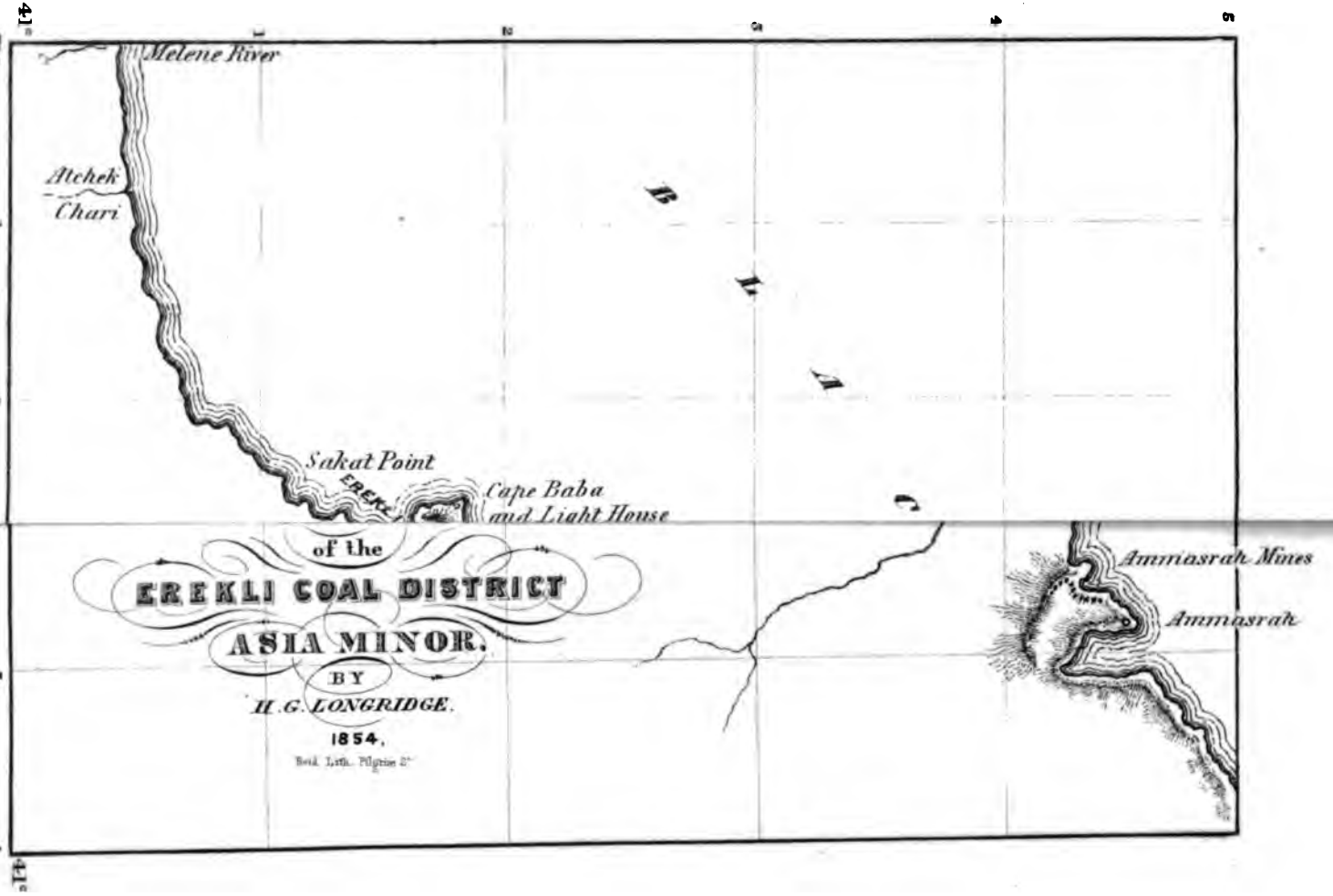
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Atchek
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Cape Baba
and Light House
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of the
EREKLI COAL DISTRICT
ASIA MINOR.
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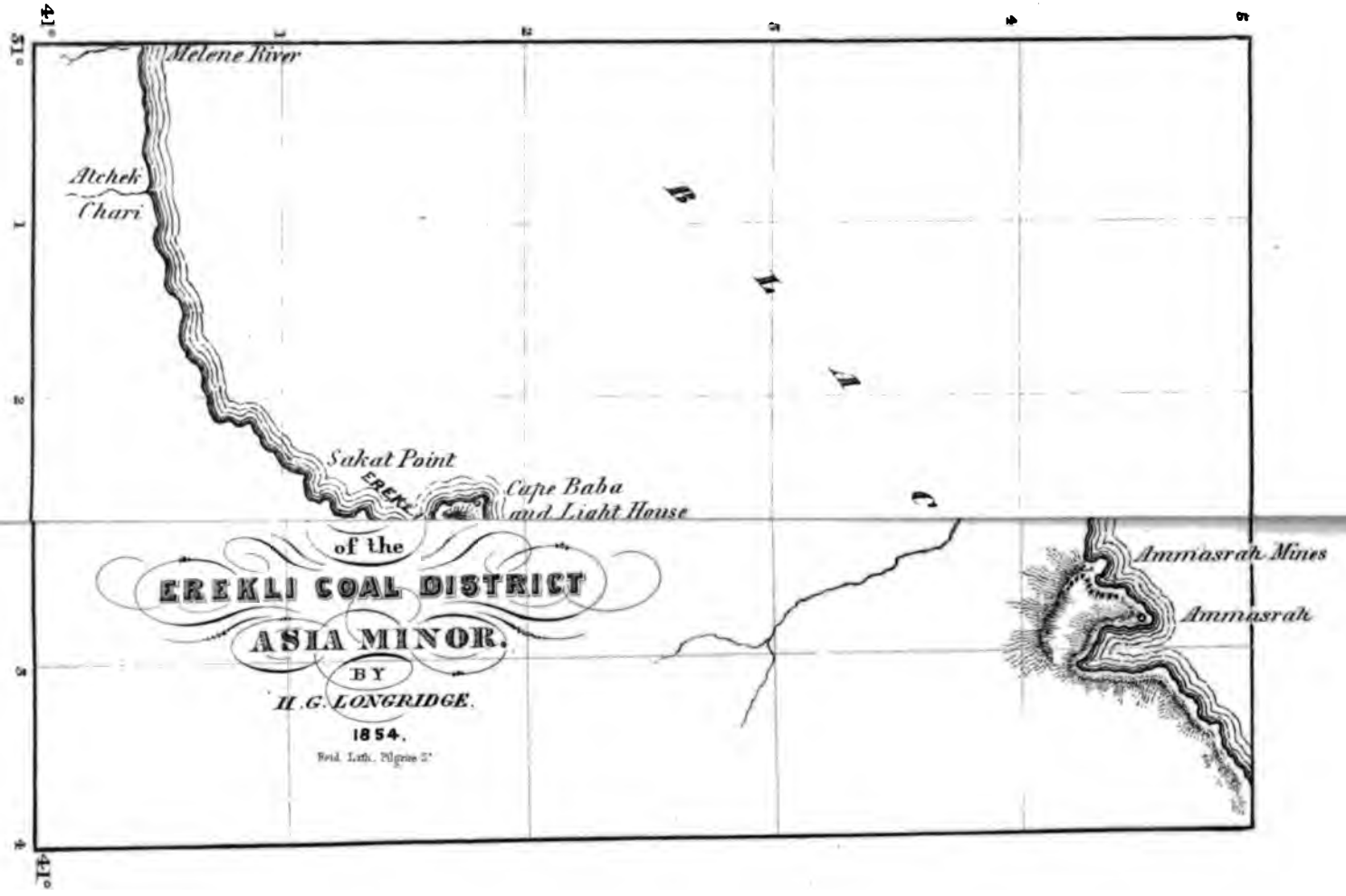
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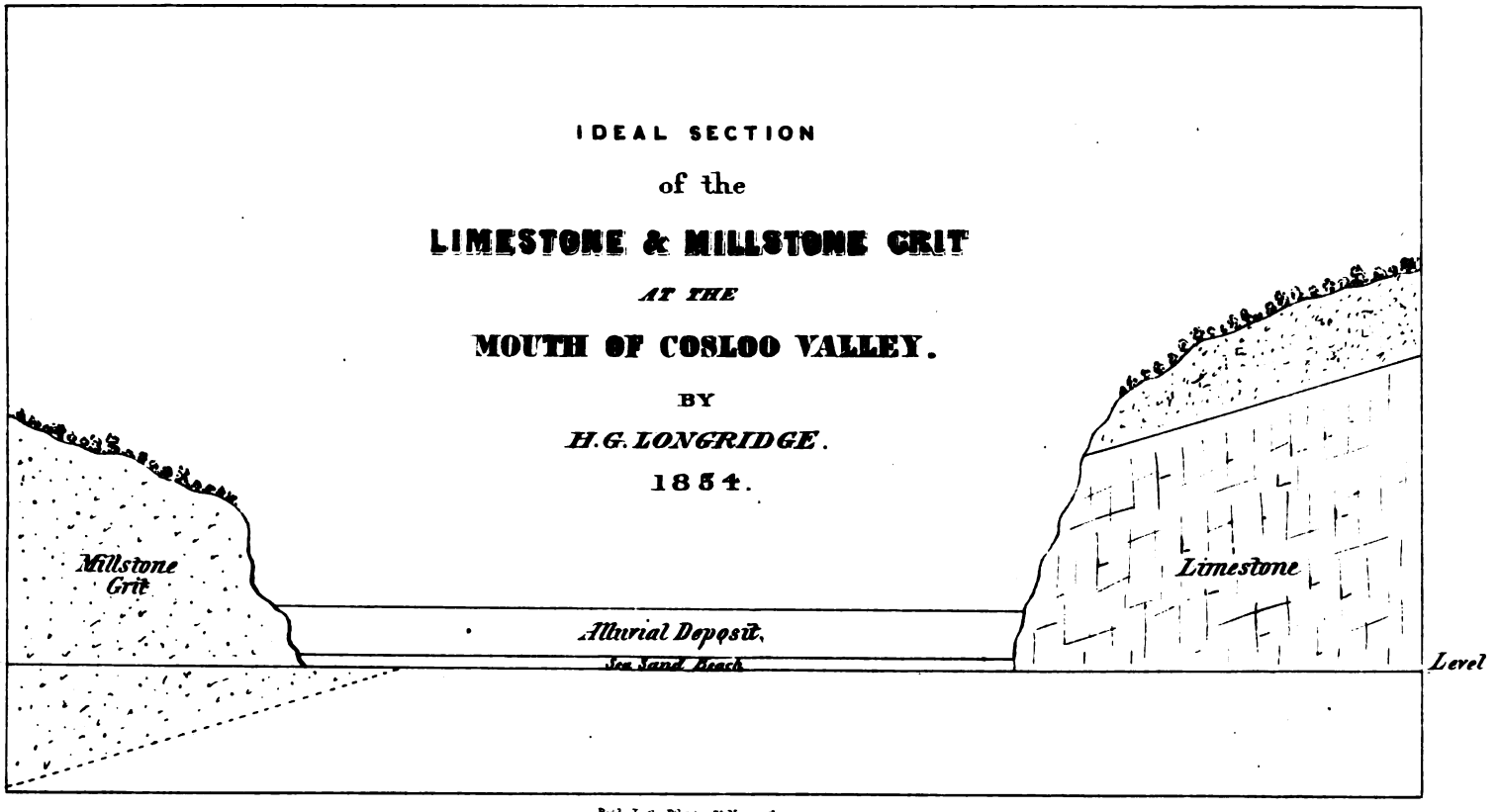

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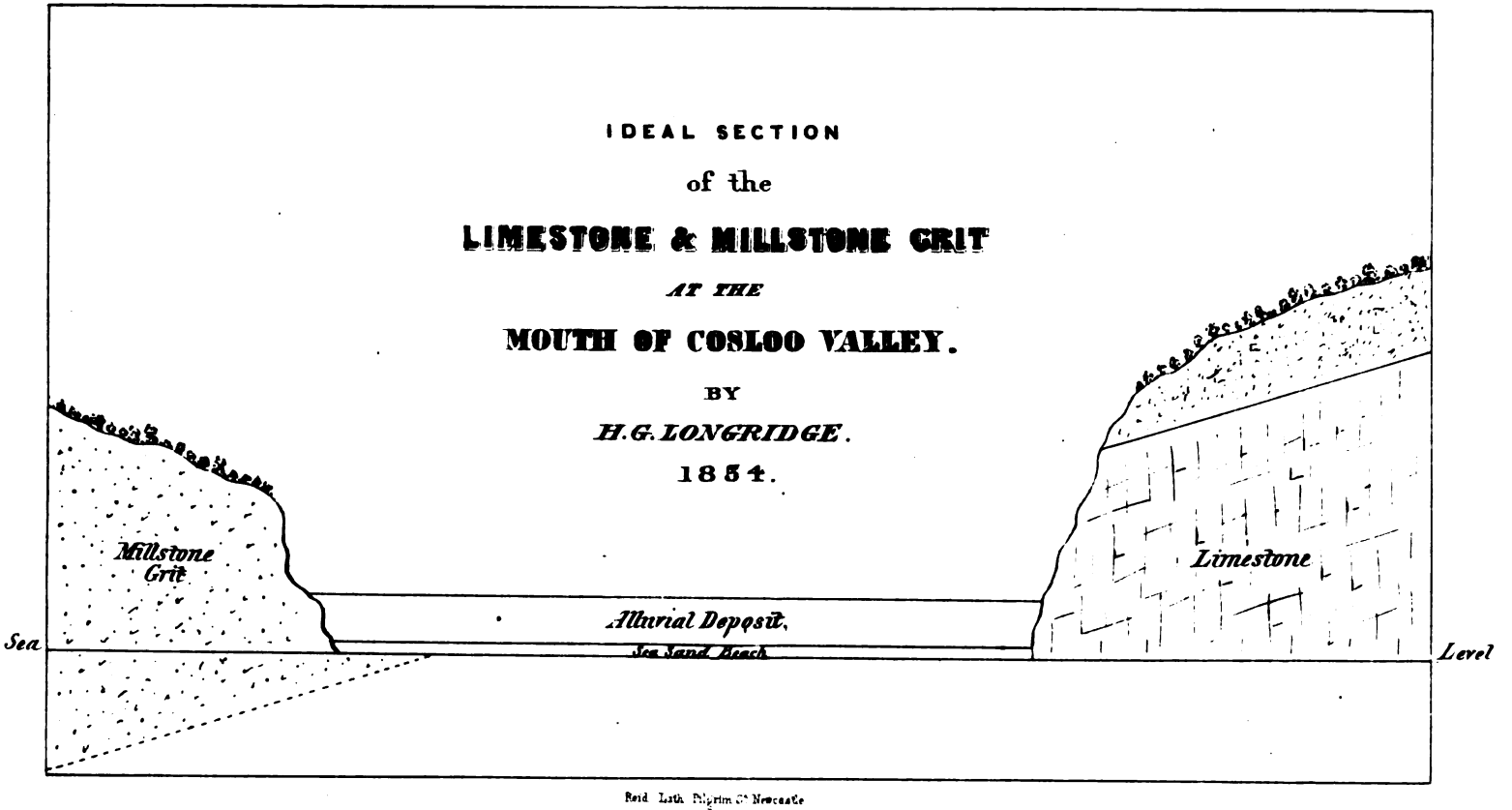

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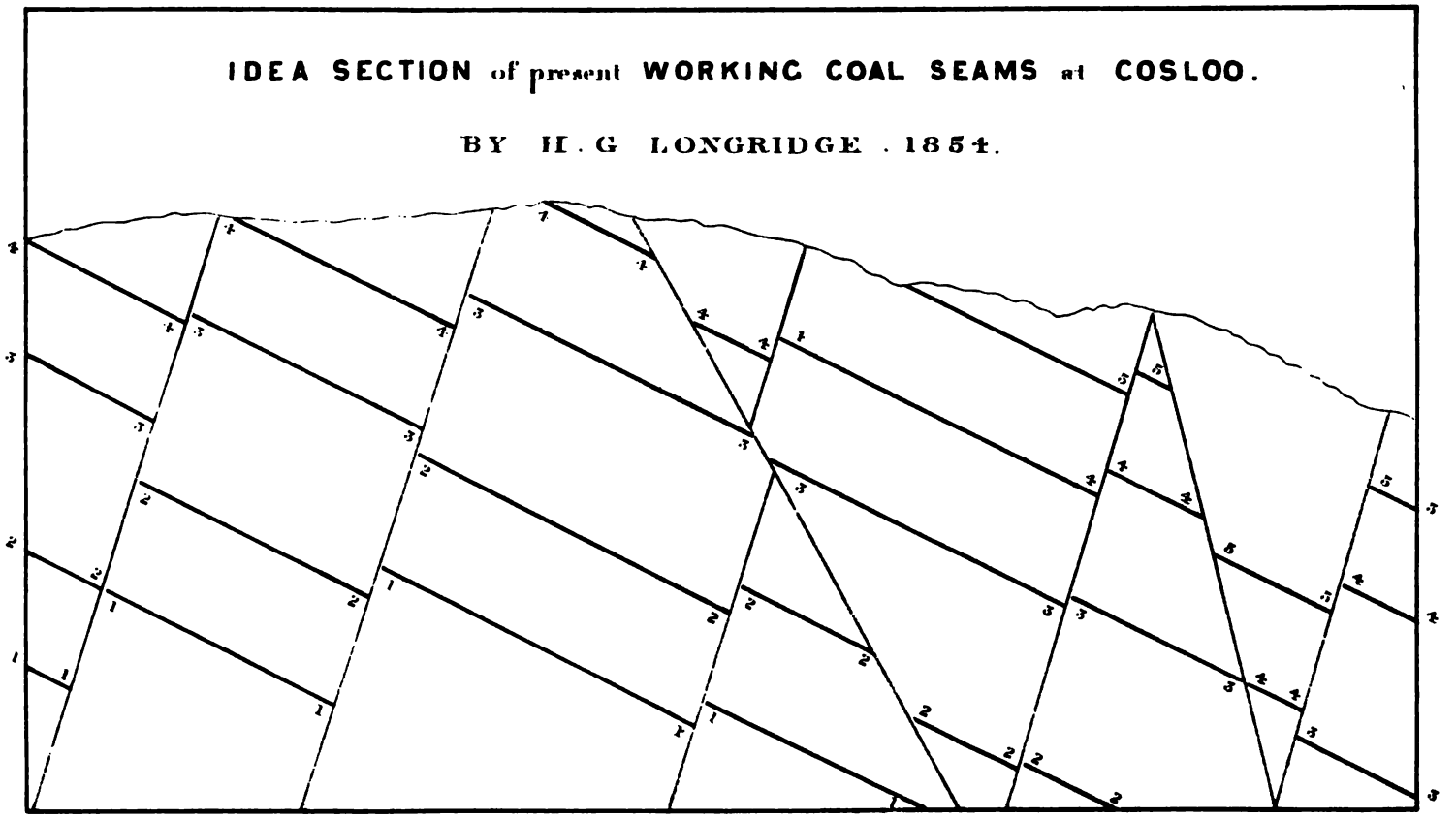
IDEA SECTION of present WORKING COAL SEAMS at COSLOO.
BY H. G LONGRIDGE . 1854.

NOTES
ON THE
COAL DISTRICTS
OF
EREKLI (ANATOLIA), & RODOSTO (ROUMELIA),
IN THE
OTTOMAN EMPIRE.

BY H. G. LONGRIDGE.

In venturing to comply with the desire of the members of this Institute, to give some account of the coal fields of the Ottoman Empire, now a country on which the attention of the whole world is rivetted with intense anxiety, I must apologize for the very imperfect manner in which I can only bring such information before you, and beg you to bear in mind that it was collected in travelling through an extremely mountainous district, destitute entirely of roads, and covered with one dense mass of forest and underwood, during wretched weather, in the months of November and December, and that except where the principal mine now is I had no opportunity of further exploration.

Another and most serious difficulty I encountered was in having to draw all the information from the miners I found partially working the mines, through an Interpreter not over well skilled in English, and entirely devoid of any mining knowledge, so as may be well supposed I received sometimes rather incomprehensible information. Hoping at some no distant day to give more accurate details respecting those mines which are now producing the coals for the combined fleets in the Black Sea, under the working of Her Britannic Majesty's Government; I shall merely abstract from my journal, adding such remarks as may be necessary from matters subsequently come to my knowledge.

It will first be as well to notice the method in which these mines had been worked previous to my visit in 1850.

The monopoly of the coal in the Erekli (Heraclea) district, situated in Anatolia, on the south coast of the Black Sea, belonged to the Sultana Validè, and other members of the Imperial family, with one or two of the influential Pashas.

Any person was allowed to open out a seam, and received a certain sum per cantar (120 lbs.) for the coal on the sea shore; hence arose the system adopted throughout of working without either skill or capital.

The principal masters or workers of these mines are Croats or Montenegrins, who formerly had been brought over to quarry stone at Constantinople, but on the discovery of these mines were sent up to them.

Any one having discovered a coal seam within distance of easy carriage to the sea, applied to the mine Director for leave to work it, which being obtained, the working commenced by following in the seam from the outcrop as far as practicable for water or the roof falling in; in very few instances did I find a place holed round, and they had invariably begun at the top of the mountain and worked downwards.

The coal being hewen, is carried out on men's or boys' shoulders in small baskets, each containing about 30lbs. or 40lbs. of coal, or in case of a large piece, it is slung, and so carried out alone.

The coal was thrown down as near the drift mouth as a convenient place occurred for mules, horses, or bullock waggons to come for them. As soon as the master of the mine thought he had sufficient quantity laying in heaps, which might be three months or more, he applied to the mine Director for the horses, mules, &c., to be sent to convey the coal to the sea shore, where it was carried by them in panniers, and again thrown into heaps as soon as weighed. This heap was constituted of the produce of all the neighbouring drifts or mines, and neither screened or wailed.

When a ship arrived, the coal again underwent the process of being carried in small baskets to boats containing 4 to 5 tons each, and thence off to the ship, where the baskets were again resorted to, to put it on board, next the voyage, another boating and basketing, and at last the coal was deposited in the depôt or magazine to await the final basketing and boating for consumption. Such being the process, and all bands, pyrites, &c., &c., going in together, as well as most of the best seams being naturally tender, it can scarcely be wondered at if the report from two of Her Majesty's steam vessels announced it *utterly worthless.*

The village or town of Erekli is situated about 100 miles from the mouth of the Bosphorus, and is also marked on many maps Penderaclia and Heraclea, and contains the only safe refuge for ships on the south coast of the Black Sea, between the Bosphorus and Sinope; and although an open bay, has deep water close to the shore on the most sheltered side, where a large depôt could easily be made, and the largest ships coaled at any time by spouts with little expense or difficulty.

Before getting to Erekli, however, I should mention a valley called Donghûs Dereh, from which I received specimens almost similar to the coal of Rodosto, and entirely different from the coal of Erekli. This valley is close to the mouth of the Bosphorus. I entertain little doubt that this then approximates the eastern limit of the coal field extending west to Lamsaki, and the shores of the Archipelago and north of Marmora, by Gallipoli, Rodosto, to Adrianople.

The whole of the coal district from Erekli to Amasserah has been violently disturbed subsequent to the coal formation, hence throughout the whole district the seams vary in position from perpendicular to an angle of 20°; also frequently doubled over like a horse shoe, and twisted over and over in a space of a few hundred yards. In one place where this was remarkably apparent, the coal had been wrought as a quarry with a face of about 150 yards.

The first coal I found going East from Erekli was in some débris at Chambli, about 4 miles distant, the mines here having been some time abandoned.

The small pieces of coal were perfectly clean, bituminous, cubical fracture, and burned with a clear bright flame, and little ash; the shale was such as is here termed tender grey metal. The seam appeared to be about 4 feet thick.

A small drift not far from here is probably in the same seam which is here greatly distorted, to judge from the mouths of the abandoned drifts.

About a mile and a half further, on the top of a mountain, a 12 feet seam had been worked open cast, but appears to have contained bands varying from ½ an inch to 4 inches.

Were this seam worth working a stone water level drift would cut the seam at a short distance from the bottom of a ravine, which is very deep and underlevel a great extent, probable proving several seams instead of one.

At Alijûsah, about 8 miles from Erekli, are several seams of good coal 4 feet to 4½ feet, but apparently tender.

Over the next mountain, probably a mile and a half, lays Choùshazar, probably one of the most curious formations of coal yet seen. The valley is wider and more open than most of the others; in which a large hillock about 100 yards by 30 or 40 high, had been partially quarried away exposing a mass of broken rock run into a conglomerate, with a strong bituminous coal as the base. Large pieces, apparently all coal, on being broken were found to be merely a coating of coal over a large stone, rounded apparently by the action of water. The coal had, notwithstanding, a cubical fracture, and burnt without much flame. It is still more curious that this mass of coal and gravel appears to have been repeatedly fractured, and the cracks again filled up with coal, giving the appearance of numerous veins, each intersecting the other.

Can this be explained by imagining liquid bitumen boiling up through some ancient river bed, in an intermittent manner, and the fissures produced in the cooling by contraction, again and again filled up at different epochs. But to what can be due the difference in quality of the coal injected into these fissures, some being like jet and others granulated, and containing a portion of quartz?

On the east side of this valley are seams of 8 to 9 feet in thickness, containing numerous stone bands 2 or 3 inches apart of various thickness, and also iron pyrites incapable of separation, causing the coal to run to a strong clinker, almost a glass. Some of this coal the trial vessels had got, as the works at these mines had been allowed to go on, although condemned by me in 1850; and I this year saw a large quantity in depôt at Erekli, which was offered for the use of the combined fleets, but declined.

At about 18 miles, sea measurement, from Erekli Point, on the top of a mountain, before descending to the valley of Koslou or Cosloo, is a seam of 8 feet 6 inches thick, nearly perpendicular, and cutting the mountain ridge nearly at right angles. The quality apparently very good. This seam had been worked open cast.

Descending from this mountain, the valley of Cosloo is reached, in which the mines are at present working for the fleets.

At the mouth of this valley is a small bay with a sandy beach; bounded on the east by the outcrop of the limestone rising rapidly to the north and west, and forming an almost perpendicular cliff of great height. The opposite side of the bay is bounded by a sandstone containing quantities of pebbles and quartz, exactly corresponding to the millstone grit, and rising in the same direction as the limestone on the opposite side.

The breadth of the valley at the mouth is about 400 yards, quite level, of alluvial deposit, with a small river running down it, and gradually narrowing for about two miles until it becomes a mere gorge, and at a mile or two further turns east on meeting the mountain limestone range.

The coal exists on both sides of this valley, but is most abundant on the east side about one mile from the sea, but seams have been worked within a few hundred yards of the sea, and Mr. Barkley has now opened out one of these at the lowest level, in which, though close to the outcrop with many old drifts to the rise, strange to say an explosion of fire-damp took place, burning two men severely. This drift was not more than thirty-five or forty yards in and working to the dip. Fire-damp was previously quite unknown to the native workmen.

The seams are all of good thickness from 4ft. 6in. to 6 ft., and some more, clean coal, rising north and west. Six seams can be distinguished, but the frequent troubles render the tracing of any one peculiarly difficult. A stone drift or tunnel now in progress will cut the whole of these numerous seams at the lowest level, at distances of 100 to 150 yards, and thus win this mountain of coal as it may well be called.

The general strata is a coarse-grained sandstone, some containing pebbles and coal scarrs. Also several beds of blue shale with a few ironstone balls, and more rarely a band, but the shales seem to form a very small proportion to the sandstones.

A tramway is now laid from the mines to the sea on which the coal is transported in one-ton waggons, drawn by horses, and shipped by spout into boats to take off to the ships. As much as two hundred tons has been shipped in one day.

Tubs and trams have been introduced into the mines, and a proper system of water levels established.

The roof is frequently very bad and requires much timber, but there is an abundant supply in the immediate neighbourhood, the whole country being one mass of forest.

Mr. Barkley, his brother, and four men, are all the English at the mines, but eight more men are about to proceed there immediately.

Proceeding east over the next mountain range to the next valley, Zunguldak, or Soungoul, another small bay, is found, similar to that at Cosloo, but bounded by the coarse sandstone or millstone grit on each side.

On the west side, a short distance from the shore, a seam, formerly

worked, was re-opening out when I was last there (May, 1854). It is a seam of 9 to 10 ft. thick of excellent coal, and looked very promising. But by far the most promising are some 5 seams of 9 to 12 feet thick of clean coal, much stronger than the Cosloo coal, and of unexceptionable quality; the inclination is also less, being about 20°. The position of these seams has hitherto prevented them being worked, being about five miles from the sea, so that a railway would be required; this is however, perfectly easy of formation along the bottom of the valley to an excellent place of shipment.

There can be no doubt that both sides of this valley contain other large and numerous seams, hitherto unworked for want of means of transport to the sea.

For 9 miles further east the coal seams (outcrop) continually make their appearance, but few have been worked. One I saw of 20 ft. thick, but containing stone bands, and many of the other seams gave evidence of iron pyrites.

At Châtâlâlsy the limestone again puts in, cutting off the coal measures say about 28 or 30 miles from Erekli by sea measurement.

Descending from this ridge a plain of great extent of alluvial deposit is met with, through which a fine large river, the Filios, runs. This plain and marsh extends almost for 25 or 30 miles, and in it is situated the town of Barton, 9 or 10 miles east of which are the Amasserah coal mines said to have been worked by Belgian or French Engineers. There are several seams here, but contain large quantities of iron pyrites in the joints of the coal as well as in lumps, so much so as to render this coal almost worthless, as well as dangerous from liability to spontaneous combustion, a case of which occurred from that cause in one of the depôts at Constantinople during my first visit.

This is as far east as has yet been explored for coal to my knowledge.*

The Cosloo mines now produce about 20,000 tons per annum, but with a few more skilled European workmen may soon be capable of producing 40,000 tons, and when the tunnel is complete 100,000 per annum may be obtained.

The former cost was 3 piastres per cantar on the shore, and the same for transport, or about 20s. per ton at Constantinople for what was almost worthless. Coal of excellent quality could be put on board at 5s. to 6s. per ton working charges, notwithstanding the high wages of European workmen.

* It will be observed that Dr. Lyon Playfair mentions a specimen from Bolon, Castamoni—No. 3275—which place is considerably further East.

This coal makes excellent coke, and, being free from sulphur, would be admirably adapted for blast furnaces, and there is no want of iron ore and limestone.

In concluding my remarks on this coal district, there appears scarcely a doubt that it belongs to the true coal formation immediately overlying the millstone grit, but which does not here appear to be of great thickness. The examination of the fossil and organic remains would be of great value. And these I hope to have forwarded, as well as various specimens of the strata and coal seams, ere long.

ON THE RODOSTO COAL DISTRICT.

Rodosto, from which I have named this district, is situated on the north coast of the sea of Marmora, about 90 miles from Constantinople.

Six or seven miles west of Rodosto, the country is mountainous, but I did not approach near enough to ascertain their nature.

The whole of the country eastward is constituted of long undulating steppes, very barren of trees, with a *red yellow marly* soil, containing many stones, resting on a very friable sandstone, and elevated from 50 to 200 feet above the sea. This sandstone where exposed exhibits numerous small hillocks like mole hills, composed of concentric layers, exactly similar to an onion.

Commencing with some mines said to have been formerly worked for the powder mills, but abandoned in 1847 or 1848, which are situated about 2½ miles west of Rodosto and 1½ from the sea of Marmora, I found considerable quantities of coal in abandoned heaps, and also much shale in waste heaps. The reason assigned for the abandonment of these mines was the water being too heavy for them; the seam dipping rapidly into the hill. There were several old pumps remaining, formed of trees bored through, 4 to 6 inches diameter. This coal had a perfect cubical fracture, was rather lustrous, but only ignited with great difficulty, and then smouldered rather than burnt to a red brown ash, retaining the form of the original piece, and falling to dust when touched. As this seam gave every indication of being similar to that on the east of Rodosto, where I was enabled to see it in the face of the abandoned workings, I shall proceed to describe it there.

For upwards of a mile east of Rodosto a coal seam is visible, cropping out along the sea cliffs at a height of about 30 feet above water line, dipping from the sea north at about 20°. It will therefore soon run under

the sea level. This seam is about 3 feet 6 inches, between two beds of very friable yellow sandstone, streaked with red veins, easily disintegrated, and wasting rapidly by the action of the weather: quality of the coal, same as that already described. About 14 miles further east, I had again an opportunity of seeing this seam or one very similar; the greatest difference being less lustrous and without the cubical fracture of the former seams. I here obtained the following section.

Section of strata taken about six miles west of Erekli (Roumelia), on the north coast of the sea of Marmora, May, 1854:—

			Ft.	In.
Surface soil—red marl and sand, very stony.				
Coarse friable sandstone			5	0
Blue shale			3	6
Coarse sandstone			3	0
Coal parting			0	0½
Blue shale			2	0
Coarse sandstone, with strong girdles			5	0
Blue shale			8	0
Sandstone			4	6
Blue shale, mixed with sandstone			6	0
Coal	3 0			
Seggar clay	1 6		5	0
Coal and stone	0 6			
Seggar clay			3	0

SEA LEVEL.

Thick bed of sandstone, cropping out and forming a sort of reef in the sea.

The coal is here at one place bared by the sea, and rises south-east.

Six miles further east is the town of Erekli, and 14 miles further is Silivria, where I again obtained specimens, and the following section:—

SURFACE SOIL.

	Ft.	In.
Sand	6	0
Sandstone	14	0
Alternate bands of sandstones and shale, with ironstone balls	6	0
Seggar clay	3	0
Sandstone, overlying coal seam	12	0
Coal	3	0

Some English gentlemen, Messrs. Laing, are said to have opened out these mines some years ago, but they have evidently never been worked.

I found great difficulty in obtaining information on account of the natives having been compelled to work the mines in former times without pay, and fearing being compelled to do so again, if they were recommenced.

Having ascertained the worthlessness of the coal in this district for steam purposes, in comparison with those already known to me, on which point it was my sole object to acquire information, I was obliged to hasten

may return without further investigations into the interior; but I have it from good authority that coal corresponding with this exists in the neighbourhood of Adrianople, and on the opposite side of the Marmora, as well as on the Island, the same description of coal is found.

I shall conclude this paper by appending an extract from the reports by the juries of the Great Exhibition, and Dr. Lyon Playfair's reports on the different specimens sent to that Exhibition, and subsequently examined by him.

November 2nd, 1854.

DR. LYON PLAYFAIR'S REPORT ON TURKISH COAL SPECIMENS.

Marlborough House, 15th April, 1854.

I.—AMASSORA COAL.

Amasserah, Black Sea. This coal is bituminous in character, not unlike ordinary Newcastle coal. In the specimen, which may however be deteriorated by keeping, it is too friable, that is in a ship's hold it would be apt to rub down small; it burns with much smoke, which is objectionable for war purposes, as it enables the enemy to see the ships at great distances; it lights easily, which is a useful property in getting up steam quickly, and burns with a good deal of flame. It leaves on burning 3½ per cent. of a lightish red-brown ash—this amount not being larger than many kinds of coal in this country.

GENERAL REMARKS.

This coal may be classed (so far as may be judged by the burned specimen) as an ordinary variety of Newcastle coal, but considerably inferior to the Welsh steam coals.

II.—RODOSTA COAL.

Sea of Marmora. This coal is quite of a different character, more nearly resembling Welsh anthracite. It is difficult to light, but burns readily enough when ignited. In burning it produces little flame, and almost no smoke. It leaves 7½ per cent. of ash, or more than double the quantity of the previous coal—it is also too friable; but this may be from the specimen having been weathered.

GENERAL REMARKS.

In some respects this coal is preferable to the other for war purposes, if the furnaces of the steam vessels are fitted to burn it, which is a doubtful question. If they are, notwithstanding its greater quantity of ash, one pound of this coal will probably evaporate as much water as a pound of the former. It is not, however, suited for getting up steam quickly, which is objectionable; but, on the other hand, it is less likely to betray the approach of the fleet to the enemy.

So far as the hard specimens are to be trusted, I give you all the deductions that may be fairly made from them, but you are probably aware that in general these are insufficient to decide the quality of coals. The best and only reliable test is to put them under a boiler and see how they work, with special forms of furnace.

Both specimens, however, give promise, and are worth looking after, though the Newcastle variety is not equal to our best Newcastle coals, nor is the anthracite variety equal to our good Welsh anthracites.

I send you the Turkish catalogue, and if you wish the other specimens when they are identified to be examined, I shall be happy to do them for you.

Marlborough House, 18th April, 1854.

I now send you a general examination of the other coals sent to me, those from Amassora and Rodosta having been already examined.

No. 3268—From DRAMA.

This is not a coal but a bitumen, very similar to Trinidad pitch. In its ordinary state it cannot be used for steamers, but Captain Cochrane (now commanding a ship in the Baltic, I believe), has recently discovered a method by which such bitumens may be advantageously burned in steamers. If this abounds, it might be worth while to procure from Lord Dundonald (father to Captain Cochrane) a description of the plan which the latter has so successfully carried out at the Admiralty and in the river steamers.

No. 3275—BOLON, CASTAMONI.

Asia Minor, Black Sea. This is a hard, very lustrous, and not too friable coal. It burns with a bright flame, and only moderate quantity of smoke. It cakes in burning—has a dark-red coloured ash, which amounts to 3·34 per cent. This is, on the whole, a very good specimen.

No. 3276—VIRANSHER, ASIA MINOR.

This coal very much resembles the preceding, being hard and lustrous. It burns with much flame, and a good deal of smoke, not more however than a common Newcastle coal. It swells in burning—keeps in well when lighted. It gives an ash (very like the preceding specimen) dark red, and only amounting to 1·78 per cent. This is a promising specimen of coal.

With reference to my previous letter you will be able to compare these coals, and will only accept the descriptions as probable indications of the value, but not as dispensing with the necessity of experiments under the boiler.

Black Sea. I have caused the most strict search to be made after the specimen of coal from Erekli, and if it is found I shall examine it, and forward the result to you.

Marlborough House, 18th April, 1854.

We have proved by the original register that the EREKLI coal was never given in to the Exhibition. We have found, however, six new ones:—

No. 3307—A coal from MOLDAVIA;
,, 3272—Coal, or rather a lignite from MONASTIR;
,, 185—Coal, from MOUNT LEBANON;
,, 2214—Coal, from TRIPOLI, BARBARY.

I presume that these are too far from the scene of action to be worth analyzing; but if you think they had better be examined I shall do so with pleasure.

Dr. Playfair to Sir C. Trevelyan.

Department of Science and Art.

I have examined the remaining Turkish coals, which we were able to identify by the Turkish labels and numbers upon them, and now send you the results.

Two of the coals are marked 3307, and described as coming from Moldavia. Both of them are inferior coals, containing a good deal of iron pyrites, and from 7 to 9 per cent. of ash. They burn with a moderate amount of flame and smoke, but on the whole are very inferior to the specimens of coals formerly examined.

Macedonia. Two, if not three, coals were marked with the number 3272, and are described in the catalogue as being from Monastir. Two of these coals were very much deteriorated by weathering, but probably in their original state are not bad coals. They do not appear in the specimens examined to be very bituminous. One of the specimens contains 3·39 per cent., and the other 0·583 of ash. They burned without much flame or smoke, but from the badness of the specimens little reliance can be placed on the examination.

No. 185 is described as a coal from Mount Lebanon. It is black, lustrous, but contained a good deal of iron pyrites. It burns slowly and steadily, and contains 5½ per cent. of a whitish brown ash.

From the inferiority of all those specimens these results must be considered as merely rough indications of the probable value of the coals.

Erekli, Black Sea. I suppose you are aware that Captain Spratt has just been to Heraclea on special service, and that he gives a most favorable account of the coal which he describes as being equal to the best Newcastle. Specimens are expected to arrive in this country in a few days.

EXTRACT FROM REPORTS BY THE JURIES OF THE EXHIBITION OF THE WORKS OF INDUSTRY OF ALL NATIONS, 1851, PP. 35-36.

TURKEY (1885).

"The mineral exhibition of Turkey is represented by a collection of upwards of two hundred specimens, sent by the Ottoman Government. It was but just unpacked when the Jury separated, and the specimens were labelled only in the Turkish language, with which none of the members of the Jury were acquainted, so that it is impossible for them to state the precise value of the collection. It appeared, however, to be of some importance by the variety of the metalliferous ores included, the principal of them being red hœmatite in fine kidney-shaped nodules, lead ores, accompanied by metallic lead obtained from them, and rather rich copper pyrites." But that which has chiefly interested us, and requires special notice in this place, is the presence of twenty or thirty specimens of very good coal, and the person in charge of the collection having had the kindness to translate for us the labels, we are enabled to state the localities whence they were obtained. All of those localities are distributed over a range of upwards of forty leagues along the shores of the Black Sea, the Sea of Marmora, and the Archipelago, whence it appears that the coal formation must have a wide distribution in this part of the Turkish empire. The names of the places, beginning from the

east, are as follows:—Amastra, and Erekli, on the Black Sea; Vivan, on the Sea of Marmora; and Scala Nova on the Archipelago, about forty miles from Smyrna. There are also in the collection three specimens from Rodosto in the Roumelia, twenty-eight or thirty leagues west of Constantinople; so that if the indications of these localities may be depended on, the coal formation must exist on both sides of the Straits, but according to a geological collection from the shores of Amasserah and Erekli, collected in 1844, and deposited in the Ecole des Mines in Paris, by M. de Chancourtoi, Mining Engineer, there is reason to doubt whether the mineral fuel from the shores of the Black Sea (Anatolia), belongs to a true coal formation, and it is possible that the deposit is as modern as the cretaceous period. However this may be, and although it is possible that mistakes may have arisen by confusing the place of production with the port of embarkation, it appears at any rate, quite certain that Turkey possesses, at a small distance from the capital, and even on the channel of Constantinople a considerable coal field, which may become an important source of wealth in the development of its industry and for the purposes of steam navigation.

(Signed) DUFRENOY, Reporter.

Paris, 1st October, 1851.

(COPY.)

Admiralty, 17th July, 1854.

Black Sea.

SIR,—I am commanded by my Lords Commissioners of the Admiralty to acquaint you, for the information of the Lords of the Treasury, that some specimens of coal from the mines near Heraclea have been tested in Portsmouth Yard, and the result appears to be that, though inferior to Welsh and Newcastle coal, this coal is considered equal to many of the Inland and Scotch coals.

I have, &c.,

B. OSBORNE.

January 4th, 1855.

Since bringing the above paper before the Institute I have received the specimens from the Rodosto district, and annex the specific gravity of various specimens. I hope by the next meeting to lay before the Institute the analysis of several pieces of the coal from each of the places whence I obtained the specimens.

No. of Specimen.	Locality.	Sp. Gravity.
1	SILIVRIA	1·285
2	"	1·324
3	"	1·250
4	EREKLI (MARMORA)	1·297
5	"	1·333
6	"	1·282
7	RODOSTO (EAST)	1·353
8	"	1·353
9	"	1·376
10	RODOSTO (WEST)	1·425
11	"	1·378
12	"	1·425
13	"	1·466
14	"	1·378

Professor Hitchcock gives the analysis of the Erekli (Black Sea) coal as follows:—

Carbon	62·40
Volatile matter	31·80
Ashes	5·80
	100·00

Assay Office Laboratory, Newcastle-upon-Tyne, 11th Jan., 1855.

DEAR SIR,—We have the pleasure to hand you the results of our examination of the four samples of coals from Turkey.

Constituents.	Silivria, Sea of Marmora.	East of Rodosto.	West of Rodosto.	Erekli, Sea of Marmora.
Gaseous matters	49·50	48·00	48·00	52·00
Fixed carbon	43·50	40·00	47·00	40·50
Ashes	7·00	12·00	5·00	7·50
	100·00	100·00	100·00	100·00
Sulphur, P.S.	·40	·66	·29	1·53
Specific gravity	1·346	1·530	1·442	1.402

In coking, none of the samples caked in the least, and the ash is of a reddish colour.

The coals are evidently better adapted for the manufacture of gas than for any other purpose.* The proportion of sulphur is not large.

They will also answer for raising steam, but in practice they will not be so lasting as the English coal, the proportion of fixed carbon being relatively so small. They will also burn readily, and, as far as we can judge from the ash, they will not form clinkers.

We are, yours truly,

RICHARDSON & BROWELL.

H. G. Longridge, Esq., Northern Mining Institute.

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* I much doubt the illuminative power of the gaseous matters.—H. G. L.

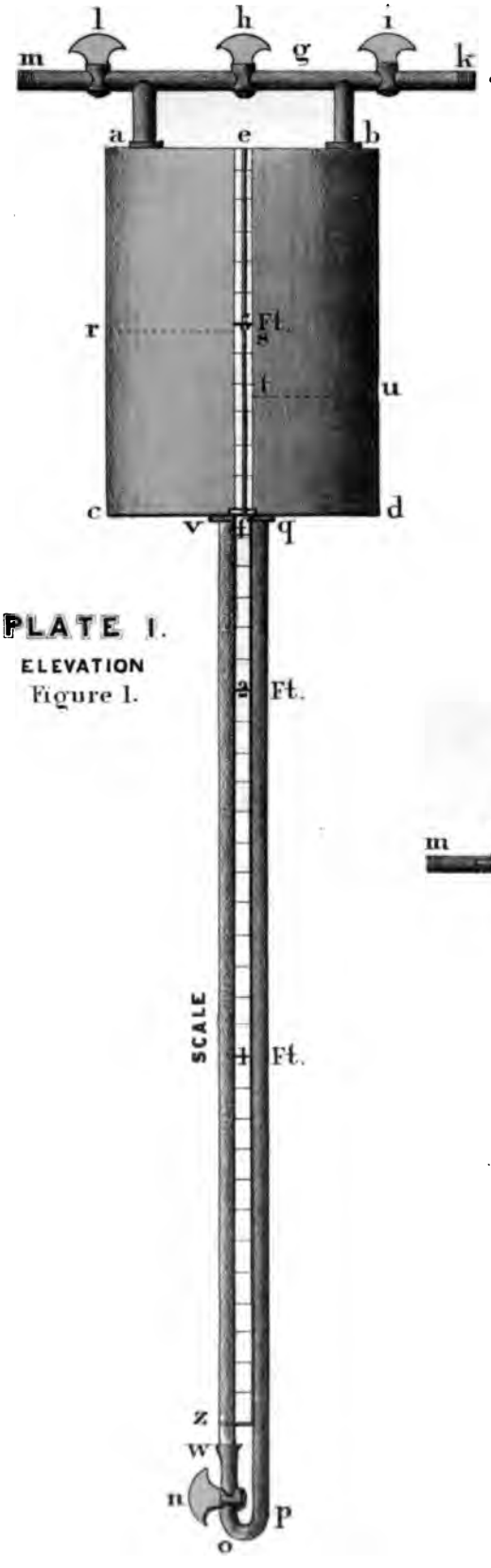


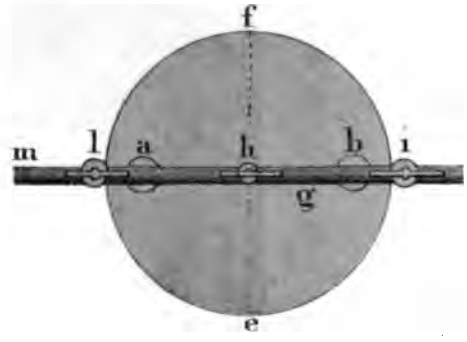
PLATE I.

ELEVATION

Figure 1.

PLAN

Figure 2.



Ford Lith. Pilgrim St. Newcastle

LIBRARY

PLATE 2.

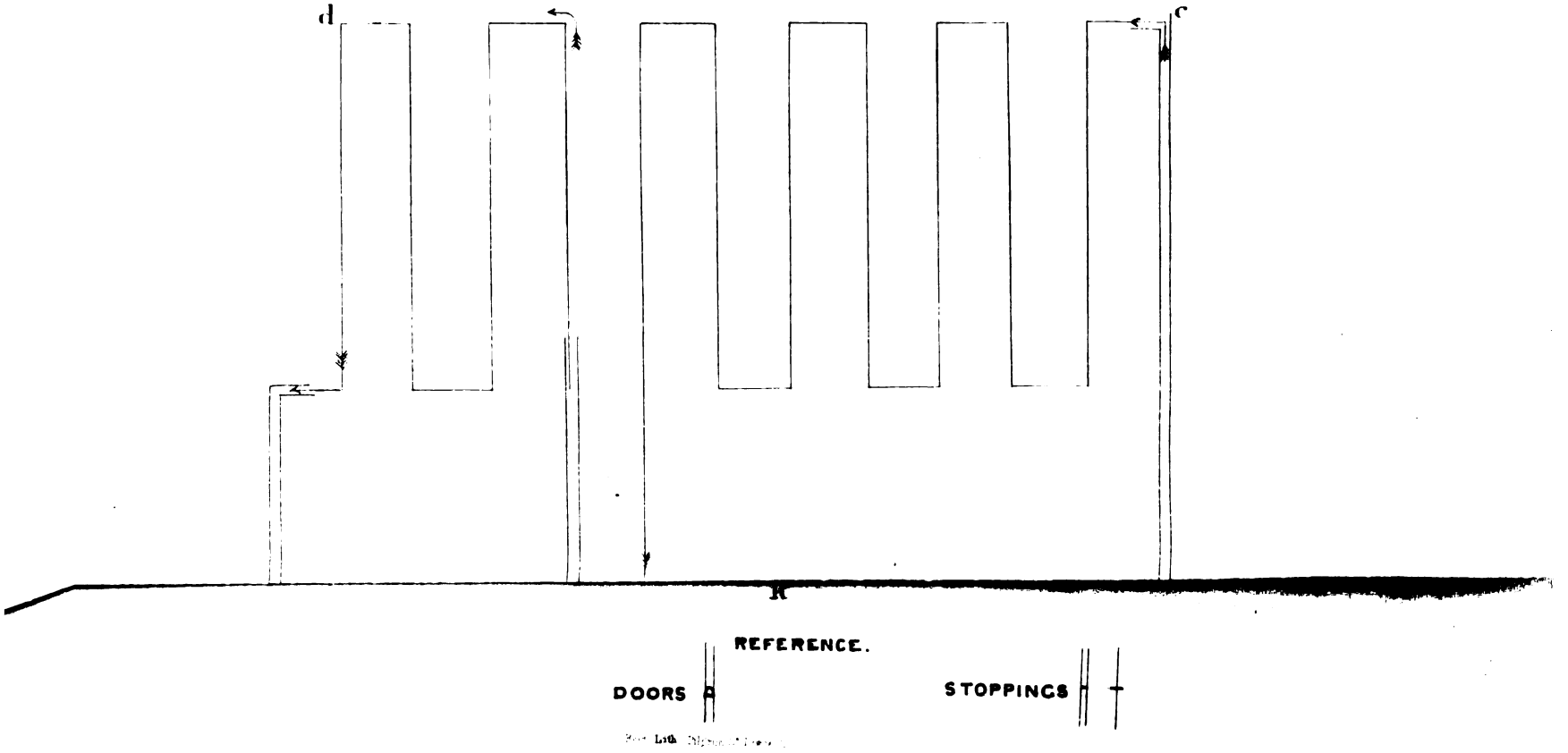
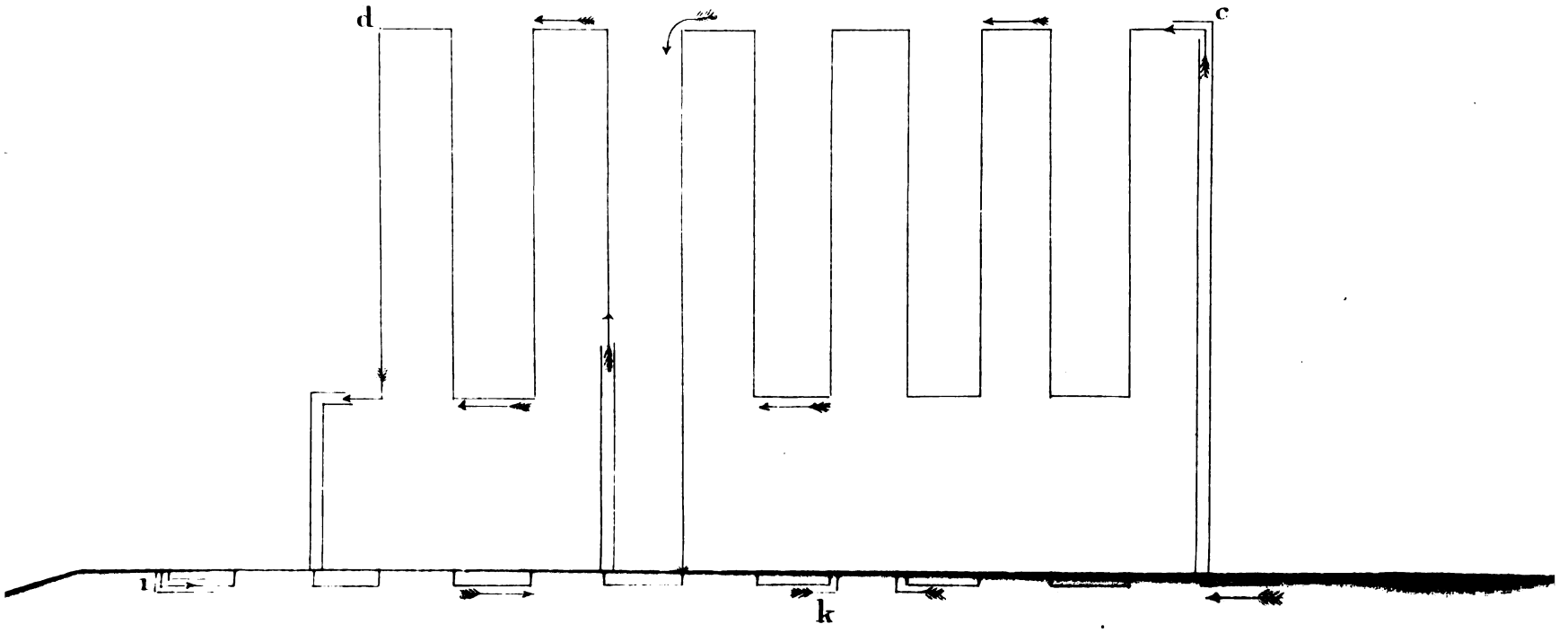


PLATE 3.



REFERENCE.

STOPPINGS

Reid Lith. Pilgrim St. Newcastle

ON THE THEORY

OF THE

VENTILATION OF MINES.

BY J. J. ATKINSON.

CHAPTER I.

Introductory Remarks—enumeration of the Principal Physical Laws which affect the Ventilation of Mines.

Some persons, who are engaged in the daily practice of an art, after observing a few failures on the part of those who have attempted to introduce improvements based upon false hypothetical views of the art, come, at length, to consider that no benefit can result from a knowledge of the true theory of their art; whilst others go so far as to look upon any such knowledge as being positively injurious, and only calculated to mislead those who pay attention to it, alleging that theory and practice never agree with each other.

That the views just named are incorrect, may perhaps appear from considering that it is only by a knowledge of the true theory that the practice of any art can be so conducted and regulated as to be certainly free from empiricism.

The practice of any art can only be improved, in a direct and systematic manner, by the application of its true theory, in the absence of which, improvements can only be expected to result from accidental discoveries, or, at best, from random experiments, coupled with a generalization which can only be regarded as a partial theory.

It is only by the application of the correct theory of an art that the results of new, and hitherto untried arrangements and conditions in practice, can be foreknown and predicted.

A correct and perfect theory will always be found to agree with the results of practice; and it can only be when hypothesis is confounded with theory, or when the theory is imperfect or incomplete, that errors can result from allowing it to regulate our practice.

While it is freely admitted that something more than a mere acquaintance with the true theory of an art is generally required to lead to success in practice, it is not, perhaps, claiming too much for theory to say that it is the most useful handmaid of practice.

Considerations of the above character will, it is hoped, be accepted as an apology for troubling the members of the Northern Institute of Mining Engineers with an epitome of the physical laws of ventilation; accompanied by formulæ for making various calculations in reference to that subject, with examples illustrating their application; and, finally, with some suggestions as to the possibility of making the theory of ventilation, to some extent, useful for regulating its practice.

Enumeration of the Principal Physical Laws which affect the Ventilation of Mines.

(1.) The volume assumed by a given weight of air is inversely proportional to the pressure on each unit of surface, under which it exists, so long as the temperature remains unaltered; so that under a double pressure air only occupies one half the space; under a treble pressure it occupies only one-third of the space—and so on; as a consequence, the density or weight of a given volume of air, varies directly as the pressure on each unit of surface under which it exists, when the temperature remains constant; so that, by doubling the pressure under which air exists, we double its density; and by trebling its pressure, we treble its density—and so on; provided its temperature remains constant, while the pressures are altered. This is known as the law of Mariotte.

(2.) When the pressure is constant, the increase of volume imparted to air by heat, is uniform and equal for each degree of heat; and the experiments of Magnus, those of Regnault, and those of Rudberg, show that the expansion caused by each degree of Fahrenheit's scale is about 1-459th part of its volume, at zero of Fahrenheit's thermometer. So that if a quantity of air, existing under a constant pressure, be conceived to be divided into 459 equal parts, when the temperature is zero, or 0°, on Fahrenheit's

thermometer; then, on heating it to a temperature of 1°, it will expand so as to occupy 460 of such parts; on heating it to 2° it will expand so as to occupy 461 of such parts; and in general on heating it to t° it will expand so as to occupy 459 + t° of such parts. This is commonly called the law of Gay Lussac.

(3.) The velocity with which compressed air escapes through an orifice, in a plate so thin as to offer no sensible frictional resistance to its passage, has been found, in experiments by M. Daubuisson and others, to be equal to the velocity which an unresisted gravitating body would acquire, by falling through the height of a vertical column of air, of the same density as the flowing air, just capable of producing, by the mere insistent weight or gravitation of its parts, a pressure on each unit of surface exposed by its horizontal base, exactly equal to the excess of pressure on each unit of surface under which the compressed air exists, over that under which the medium exists, into which it is allowed to flow or escape.

(4.) M. Daubuisson found that when air is discharged through an orifice, or a tube so short as to offer no sensible resistance to its passage, the stream of flowing air suffers a contraction, similar to that which is well known to obtain in the discharge of water and other liquids, which has the effect of reducing the quantity discharged in a given time, below that which would be due to the velocity if it existed over an area equal to that of the orifice or tube.

This contraction of the flowing vein or stream is termed the *vena contracta*, and in the case of air and gases is found to reduce the discharge to

·65 of that which would be due to the velocity, if it took place over the entire area, in the case of an orifice in a thin plate; to

·93 of that which would be due to the velocity, if it took place over the entire area, in the case of a short cylindrical tube; to

·95 of that due to the velocity, if it took place over the entire area of the smaller end of a short conical tube, of the form of the flowing vein or stream; so that the real quantities discharged in a given time, are to those which would be due to the full areas and velocities, in the ratios of ·65, ·93, and ·95 to unity, in the respective cases mentioned, according to the character of the passage through which the discharge takes place.

(5.) When air is impelled through a confined passage, the pressure per unit of surface, or head of air column, required for its propulsion, has been found by Péclet, Daubuisson, Girard, and others, to be proportional to the square of the velocity; or (what is the same, when the nature and

other dimensions of the air-way remain unaltered), to the square of the quantity of air passing in a given time, divided by the square of the area of the air-way.

(6.) The pressure or head of air column, required to propel air through a confined passage, is found to be proportional to the length of the passage, all other things being equal.

(7.) The pressure, or head of air column, required to propel air through a confined passage, is found to be proportional to the perimeter of the section of the passage, all other conditions being the same.

(8.) The pressure, on each unit of surface exposed by the section of a confined passage or air-way, or the height of the head of air-column, required to propel air through such a passage, is found to be inversely proportional to the area of the section of the passage or air-way, when all other things are equal—so that the greater the surface exposed to the pressure, the less is the amount of pressure required on each unit of surface.

If the velocity be supposed to remain constant, then since (6) and (7) represent the area of the rubbing surface, exposed to the air in its passage, by the internal walls of the air-way, it appears that the resistance encountered by the air is proportional to the area of such rubbing surface, its nature being supposed to be uniform; agreeing in this respect with the friction found to prevail in the case of solid bodies, moving with pressure upon other solid bodies; for, by (8), we perceive that the total amount of pressure required to overcome the resistance remains constant, when all other things are so, whatever may be the area of the section over which it is to be distributed; the pressure on each unit of surface exposed by the section varying inversely as the number of units of surface over which it is to be distributed—that is, as its area; so that the entire mass of moving air contained in a passage, may be viewed as if it were one body, exposing to resistance a certain fixed amount of superfices, and so requiring a fixed gross amount of pressure to be distributed over its section to overcome such resistance, when the velocity is constant; and the greater the area of such section, the less is the amount of pressure requisite to be applied to each individual unit of such area, in order to make up the gross amount of pressure required, and *vice versa;* after the same manner as the piston of a steam engine, which will require less pressure on each unit of surface to produce a given force, as the area of the piston is greater; and *vice versa.*

A law, of a similar character to this, is found to obtain, in the case of the passage of water through pipes.

(9.) The pressure required to overcome the frictional resistance, encountered by air in passing through a confined or enclosed air-way or passage is found to vary with the nature of the material composing the inner surface of the air-way, to which the moving air is exposed in its route, as well as with the mechanical state of such surface.

This law is not found to prevail in the case of water passing through pipes, or confined passages; the resistance being the same, whatever may be the nature or state of the inner surface to which it is exposed; from which it has been inferred, that the moving column of water does not rub against the internal walls of the pipe or passage, but probably against an outer, stationary film of water, adhering to the inner surface of the pipe; so that the surface against which the moving water rubs, would, in that case, always be of the same character—water; and this would account for the resistance being always the same, whatever may be the nature or state of the inner surface of pipes, through which water is transmitted; so long as the dimensions and form of the pipe, and the velocity of the water remain constant.

(10.) The absolute amount of pressure, required to overcome the frictional resistance of tubes or air-ways, to the passage of air or gaseous bodies, was found by Mons. Girard, in his experiments with the gas-lighting apparatus of St. Louis' Hospital, to be the same for the passage of the gas used for lighting as for the passage of air; rendering it highly Probable that it is the same for the passage of all kinds of gases whatever through the same pipe or passage.

(11.) I am not inclined to think that either the numerous experiments of Péclet, or any others with which I am acquainted, are calculated to determine whether the frictional resistance of air, flowing against the internal sides of an air-way, varies in any manner with a variation in the absolute barometrical pressure under which the flowing air exists, or the contrary; yet from analogy, derived from the law which is found to exist in the case of solids moving, under different pressures, against other solids, I have scarcely a doubt, but that the resistance in question is directly proportional to the barometrical pressure under which the flowing air exists. If this conjecture is a correct one, then a fall in the barometer, although accompanied by an increase in the discharge of gases in mines, and by the circulation of air of lessened density, will be accompanied by a reduction in the frictional resistance, due to the circulation of a given volume of air; so that the same ventilating pressure will put a greater volume, although perhaps a slightly reduced weight of air, into circula-

tion, after a fall in the barometer; and hence it seems rather probable, that any observed connection between a fall of the barometer and explosions of gas in mines, is more likely to have its origin in the increased discharge of gases, than in any observable reduction in the quantity of air circulating; because a fall of the barometer, will remove as much pressure, per unit of surface, from the top of the upcast pit, as from that of the downcast pit.

(12). Although the co-efficient of resistance to the passage of air through a confined air-way or pipe, as will hereafter be shown, has been found to vary to a very great extent, in cases where heated air has been used, from its value in other cases, where cool air has been transmitted *through other pipes* composed of the same kind of material, yet in these experimental trials, the condition or state of the internal surfaces of the pipes, were widely different, in the cases where heated air was transmitted, from the condition or state of the inner surfaces of the pipe, through which cool air was transmitted, so that it appears to remain doubtful whether the mere change of temperature does or does not affect the co-efficient of resistance; as the marked differences alluded to, might evidently arise, either entirely or in part, from the differences in the temperature of the air; while, on the other hand, they might arise, either entirely or in part, from the differences in the states or conditions of the inner surfaces of the pipes exposed to the moving air.

It appears to be desirable to institute a series of experiments, to determine whether a change of temperature does affect the resistance or not, as this question has an important bearing upon the best size of upcast shafts, for the purpose of ventilation.

(13.) The experiments, which Mons. Daubuisson made, to determine the pressure required to overcome the resistance to the transmission of air, through an enclosed passage or pipe, arising from mere changes of direction, at angles or elbows in the pipe or air-way, led him to conclude, that the pressure required for that purpose is always proportional to the square of the velocity, all other things remaining constant; or, what is the same, to the square of the quantity of air transmitted through any given passage in the same time. He also found the pressure required to be nearly proportional to the squares of the sines of the angles, formed by the changes of direction of the axis of a pipe. He states, however, that he did not find the pressure required to be simply proportional to the number of angles of similar amount and character; but that, although the resistance increased, by increasing the number of angles up to a cer-

tain number; yet, after reaching a certain number of angles, he states that he no longer found the addition of more angles to require an increase of pressure to overcome their resistance; but, on the contrary, he found that the pressure required was actually reduced, by any further increase in the number of angles; so that 15 angles absorbed less pressure than 7 angles of the same size and character—a result so singular and unexpected, that it, and other circumstances, rendered abortive all his attempts to ascertain the precise law regulating the amount of pressure required to overcome the resistance offered to the passage of air through pipes, arising from angles or elbows, so far as regards the combined effects of their number, size, and character.

On the other hand, Mons. Péclet, after giving the above as the result of Mon. Daubuisson's experiments, states that bends or elbows in the pipes used by himself were found to have no sensible influence on the pressure, required to transmit a given quantity of air, in a given time, through them; although he altered them for the express purpose of trying whether they did so or not; and he further states, that he has found one and the same formula answer for the passage of air through chimneys, flues, and pipes, whether they were straight or crooked, none of the elements of the formula having reference to the angles or elbows.

(14.) The pressure per unit of surface, or the height of head of air-column, required to overcome the additional resistance arising from the existence in an air-way, of a diaphragm, with an opening in it for the passage of the air (not including the pressure required to create the local increase of velocity, at the passing of the opening in the diaphragm, which opening is of less area than the adjoining air-way) was found by Mons. Péclet to be very nearly correctly expressed by the empirical formula :—

$$h=\frac{a}{A}\left\{\frac{V_2^2-V_1^2}{231,600}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

where h is the height in lineal feet of a vertical column of air (of the same density as the flowing air), which, by its mere weight or gravitation, is capable of producing on each unit of area, exposed to its horizontal base, a pressure equal to that required to overcome the resistance arising from the existence of the diaphragm in the air-way; in which formula, a= the area of the opening in the diaphragm, and A= the area of the air-way itself, on each side of the diaphragm, both expressed in superficial feet; V_1=the velocity of the air in the air-way, and V_2=that in the opening in the diaphragm, both expressed in lineal feet per minute. He found the actual loss somewhat greater than is given by the formula.

The loss of pressure arising from a diaphragm, as just alluded to, would appear to be owing *only to the increased frictional resistance* occurring at and near the opening in the diaphragm, in consequence of the extra velocity of the air, and not, in any degree, to an expenditure of *pressure, required for the generation of the extra velocity* at the diaphragm (considered as distinct from the *effects* of such extra velocity, in increasing the frictional resistance), as Mons. Péclet supposes; seeing that the pressure due to the extra velocity (excepting only when the diaphragm is situated so close to the exit-end of the air-way, that the air actually leaves the air-way with a higher velocity than that due to the entire area of the air-way itself), would only be absorbed *temporarily* at and near the diaphragm, where the increased velocity prevailed; and after the air had got beyond the influence of the diaphragm, the moving column would again have expanded the area of its section, so as to fill the entire air-way; necessarily accompanied by a diminution of velocity; during the occurrence of which, the momentum given out by the air would have assisted to overcome the resistances encountered in the air-way; so that this pressure, required for the mere increase of velocity, considered by itself, is really not finally applied in increasing velocity, but on overcoming resistances, in the form of the momentum of the air carrying it over them.

The actual loss of pressure arising from the diaphragm, being really that due to the increased frictional resistance in the *vena contracta*, as compared with what it would have been if it had not existed, any connexion between this pressure, and that due to the generation of the increased velocity at the diaphragm, being that arising out of the fact of the *resistance* itself, being increased partly in consequence of the increased velocity, and no more. A similar mode of reasoning leads to the conclusion, that the only pressure really absorbed by, and finally expended upon, the mere generation of velocity, in transmitting air through a confined passage, in any case, is simply that due to the velocity with which the air is finally expelled from the air-way, or part of an air-way, which may be under consideration; as any higher velocity, which may prevail in any preceding part of the air-way, although (at the place where it really exists), it may be considered as temporarily absorbing the pressure due to its generation, yet since the excess of velocity is reduced, and the momentum of the air given out in a subsequent part of the air-way, and since such momentum so given out, as the velocity becomes reduced, really carries the air over the resistances, to the full amount of the pres-

sure, due to the excess of velocity, it follows that it is only the pressure due to the final velocity, which is really carried off by the air, without being applied to the resistances offered by the passage.

Again, if we are considering the pressure required to overcome the resistances of only a portion of a confined passage or air-way, it is evident that if the air arrives at the commencement or entrance-end of such portion of an air-way, with any velocity greater than that with which it leaves the exit-end of such portion of air-way, the excess of pressure, due to the generation of the excess of velocity alluded to, will really be given out in the form of momentum of the air, carrying it over some of the resistances encountered in the portion of the air-way under consideration; and consequently, so much less additional pressure will be required than would have been, had the air only possessed the same velocity on reaching the air-way, which it does on leaving it.

If, however, on the contrary, the air reaches the portion of air-way under consideration, with less velocity than that with which it passes the exit-end of the air-way under consideration, then, besides the mere pressure required to overcome the resistances in the portion of air-way under consideration, there will be a further expenditure of pressure in creating the increase of velocity, which will be carried off in the form of momentum, by the air leaving the exit-end of the portion of air-way under notice or investigation; and the expenditure of pressure on such portion of air-way will therefore consist of the sum of the pressures required for the overcoming of the resistances, and for generating the excess of velocity with which it leaves, over that with which it reaches, the part of the air-way in question. But if the air enters and leaves the air-way, or portion of air-way, as the case may be, with one and the same velocity, then the expenditure of pressure will consist simply of that required to overcome the resistances, and be unaffected by any pressure connected with the mere generation of velocity, considered apart from any increase or reduction of resistances, arising out of changes of velocity, which may occur in any intermediate parts of the portion of air-way under notice, of whatever kind or degree any such changes may be.

CHAPTER II.

On the discharge of air and fluids, under pressure, through orifices or short tubes: and the pressure due to the generation of motion, considered apart from that due to friction.

(15.) It is quite in keeping with the known laws of motion, that, as has been stated, (3), the velocity of a fluid or gas, when not affected by friction, should be the same as would be acquired by a heavy body, after falling, under the influence of gravity, through the particular height required in a vertical column of the gas or fluid, in order that the pressure on its base, arising from the weight of the column, should be exactly equal to the pressure generating the motion of the fluid or gas—or, otherwise, to the excess of pressure under which the fluid or gas exists before escaping, over that of the medium into which it flows; reckoned in each case on equal areas.

In reference to the escape of water, it is stated in "Adcock's Engineers' Pocket Book":—"Supposing a very small cylindrical plate of water, immediately over the orifice, to be put in motion at each instant, by means of the pressure of the whole cylinder standing on it, and supposing all the gravitation of the column to be employed in generating the velocity of the small cylindrical plate, neglecting its own motion; this plate would be urged by a force as much greater than its own weight, as the column is higher than itself, and this through a space shorter, in the same proportion, than the height of the column. But where the forces are inversely as the spaces described, the final velocities are equal. Therefore the velocity of the water flowing out must be equal to that of a heavy body falling from the height of the head of water."

(16.) Now by the well known laws of falling bodies, if h' represent the space or distance fallen in lineal feet; v the velocity in feet per second, acquired at the end of the fall; and g the distance in feet which an un-

resisted gravitating body falls in the first second of time, which is found by experiment to be $16\frac{1}{12}$ feet near the surface of the earth; then

$$v = \sqrt{4\ g\ h'} \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

and since g is equal to $16\frac{1}{12}$ it follows that

$$v = 8{\cdot}0208\ \sqrt{h'} \ldots\ldots\ldots\ldots\ldots [3]$$

From what has been stated, it is evident that h′, in the preceding formula, will represent the height in feet, of the head of air column, of the same density as the flowing air itself; which, by the weight or gravitation of its parts, will generate the velocity represented by v.

That is to say, h′ represents the necessary height in feet of a vertical head of air column which is just capable of producing by its weight, that particular pressure on each foot of area of surface, exposed by its horizontal base, which must be exerted to produce the velocity v.

If we know the pressure per superficial foot of surface under which confined air exists, and represent it by p; and also the pressure per superficial foot of surface, under which the medium exists, into which it is allowed to discharge itself, representing it by p′; then, when the discharge is effected through an orifice in a plate so thin as to present no observable frictional resistance to its passage, or through a very short tube under the same conditions, the difference p—p′ will be the pressure per superficial foot of surface, generating the velocity; and if by w we represent the weight of a cubic foot of the air, it is evident that $\frac{p-p'}{w}$ will represent the height in feet of air column, which would be due to the pressure generating the velocity; and hence

$$h' = \frac{p-p'}{w} \ldots\ldots\ldots\ldots\ldots\ldots [4]$$

by means of which equation, the head of air column, due to any difference of pressure, may readily be found.

By transposing [3] we obtain

$$h' = \frac{v^2}{64\frac{1}{3}} \ldots\ldots\ldots\ldots\ldots\ldots [5]$$

and substituting in [5], the value of h′ in [4], gives

$$\frac{p-p'}{w} = \frac{v^2}{64\frac{1}{3}}$$

and hence,

$$p-p' = \frac{w\ v^2}{64\frac{1}{3}} \ldots\ldots\ldots\ldots\ldots [6]$$

$$w = 64\tfrac{1}{3}\,\frac{p-p'}{v^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [7]$$

and,

$$v = 8{\cdot}0208\sqrt{\frac{p-p'}{w}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [8]$$

where v is the velocity in feet per second.

If, however, v′ be allowed to represent the velocity in feet per minute, we shall have

$$v' = 481{\cdot}2\,\sqrt{h'} \quad \ldots\ldots\ldots\ldots\ldots [9]$$

and,

$$h' = \frac{v'^2}{231{,}600} \quad \ldots\ldots\ldots\ldots\ldots\ldots [10]$$

and by substituting in the latter equation, the value of h′ in [4], we obtain

$$p-p' = \frac{w\,v'^2}{231{,}600} \quad \ldots\ldots\ldots\ldots\ldots [11]$$

and hence,

$$w = 231{,}600\,\frac{p-p'}{v'^2} \quad \ldots\ldots\ldots\ldots\ldots [12]$$

and,

$$v' = 481{\cdot}2\sqrt{\frac{p-p'}{w}} \quad \ldots\ldots\ldots\ldots\ldots [13]$$

But since the velocity v′, actually prevails only over the area of the contracted vein, and not over the entire area of the orifice or tube, the quantity of air discharged in a given time will be found by considering the velocity (found as above) as prevailing only over the area of the contracted vein: so that if by c we represent the ratio of the area of the contracted vein, to that of the orifice or tube [4]; and by A the area of the orifice or tube in superficial feet; then will c A be the area of the contracted vein, where c will take the value of .65, .93, or .95 depending upon the character of the orifice or tube employed.

And if Q represent the number of cubic feet discharged per minute, then will

$$v' = \frac{Q}{cA}$$

which value of v′, being substituted in [9], [10], [11], [12], and [13], gives rise to the following series of general equations:—

$$Q = 481{\cdot}2\,c\,A\,\sqrt{h'} \quad \ldots\ldots\ldots\ldots [14]$$

$$h' = \left(\frac{Q}{481{\cdot}2\ cA}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots [15]$$

$$A = \frac{Q}{481{\cdot}2\ c\ \sqrt{h'}} \quad \ldots\ldots\ldots\ldots\ldots [16]$$

$$p - p' = \frac{w\ Q^2}{231{,}600\ c^2\ A^2} \quad \ldots\ldots\ldots\ldots [17]$$

and,

$$Q = 481{\cdot}2\ c\ A \sqrt{\frac{p - p'}{w}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [18]$$

by which the relationship existing between the quantity of air discharged in a given time, the area of the orifice or tube through which it is discharged, and the pressure employed, is exhibited.

These formulæ, however, do not apply when air, instead of being discharged without sensible resistance through orifices or short tubes, has to be propelled, in opposition to the resistances offered to its passage, through long tubes or air-ways; inasmuch as such resistances absorb a part of the pressure employed, and leave only the remainder for the generation of the velocity, considered apart from such resistances; and in mines these resistances often operate to so great an extent as to require a pressure 10, or even 20 times greater, to overcome them, than that which is actually employed in the mere generation of velocity in the flowing air.

Still, since in all cases the pressure required for the generation of velocity forms a portion of the entire pressure employed, and so requires its share of consideration in calculations as to the ventilation of mines, it has been deemed only proper to give the preceding formulæ, bearing upon this part of the subject under consideration.

CHAPTER III.

On the amounts of ventilation produced by different ventilating pressures in the same mine, and the mode of comparing the particular resistances or "drags" of different mines.

(17.) The laws recited, as prevailing in the transmission of air or gases through an enclosed passage or air-way, lead to the conclusion that the pressure required to overcome each separate source of resistance, (excluding any pressure due to the gravitation of the air in any ascending parts of the air-way, which, with the effects of the air's gravitation in descending parts of the air-way, will here be considered as diminishing or adding to the ventilating pressure employed), is proportional to the square of the velocity of the air over any given section of the air-way, and, therefore, to the square of the quantity of air transmitted in a given time through the same air-way, including the pressure due to the mere generation of motion or velocity itself; and since the sum of the separate pressures gives the entire pressure employed, it follows that, in the same mine, the quantity of air put into circulation in a given time, will be proportional to the square root of the entire amount of pressure employed, including under the term of "pressure employed," the gravitation of the air in the descending parts of the air-way, diminished by the gravitation of the air, (reckoned on the unit of surface of area only), in the ascending parts of the air-way.

(18.) The pressure finally expended on the generation of velocity in the air, will only embrace that which is due to the final velocity with which the air leaves the air-way at its exit end; inasmuch as if even higher velocities do prevail in preceding parts of such air-way, the pressure temporarily absorbed in creating such excess of velocity, will eventually be given out as momentum of the air, carrying it over resistances encountered in succeeding parts of the air-way, as must appear from the consideration that the flowing air necessarily parts with a portion of the momentum it possesses, as the velocity of its motion becomes reduced;

which momentum of itself would carry it over a portion of resistances, if no further power or pressure were applied.

What has just been stated indicates that the quantity of air put into circulation in any passage or air-way, will be strictly proportional to the square root of the entire pressure employed, (so long as the air-way remains unaltered), provided that we include, as a part of such pressure, the effects of any excess of pressure due to the gravitation of the air in all the descending parts of the air-way over that which is due to the air in the ascending parts of the air-way; always reckoning the descents and ascents as they occur in the direction followed by the air where they prevail, and reducing them to the unit of surface employed. Or, on the other hand, the entire pressure employed must be reduced by the amount of any excess which may be due to the gravitation of the air in the ascending parts of the air-way over that due to the gravitation of the air in the descending parts of the air-way, where such an excess happens to prevail.

(19.) Where steam jets or furnace action are employed, the resistance in the upcast shaft will probably increase in a somewhat higher degree than the square of the quantity of cool air in the workings of a mine, as the air in such shaft will be more expanded as the temperature and the ventilation are increased, and hence also the velocity of the air itself.

It is doubtful whether the coefficient of resistance due to friction may not be increased or diminished by changes of temperature in the upcast shaft, although Péclet did not detect any such change in it with a change of temperature.

And it may be further remarked that a mixture of aqueous vapour or steam with air in an upcast shaft may possibly modify the coefficient of resistance; although, as has been stated, it was found to remain constant for the transmission of either air or the gas used for lighting St. Louis Hospital, in Mons. Girard's experiments.

In the absence of a positive knowledge as to whether the coefficient of resistance is altered by variations of temperature or by the presence of steam in the air or the contrary, it will be presumed, in the following investigations, that the coefficient in question is not affected by such change of temperature, nor yet by the admixture of aqueous vapour.

Although the very strict investigation of the laws of ventilation would require the application of an infinitesimal analysis, yet, for all the cases which generally occur in practice in the ventilation of mines, the use of algebra will probably lead to results not sensibly differing from the

truth; and since rigorously accurate observations on ventilation can scarcely be made by any known means, the latter mode is considered sufficient for the object in view, and will accordingly be here adopted. Mathematical niceties, when introduced at all, will be intended rather to create confidence in the results than as examples to be followed when applying the deductions to practice.

Since it would greatly complicate the subject to treat the resistances as if they varied with a variation in the barometrical pressure of the air, without, for our purpose, greatly affecting the conclusions; the resistances will be treated as if they were not affected by variations in the barometrical pressure of the air; at the same time it is probable that the contrary is the fact.

Although the formulæ resulting from the mode of investigation to which reference has been made, are not, for the reasons stated, to be regarded as being rigidly applicable to the circulation of currents of air, under extreme and unusual conditions as to temperature and pressure; yet they may, perhaps, be regarded as possessing all the accuracy which can be considered desirable, as applied to currents of air under the usual conditions prevailing in mines, flues, and chimneys.

(20.) Since the pressures required to create ventilation, *cæteris paribus*, are proportional to the squares of the volumes of air circulated in a given time through the same passages or air-ways, it follows, that if, by calculation, the quantity of air which would have circulated under the same pressure over the area of the air-way, if there had been no resistances beyond the inertia of the air, be found to be five times as much in the unit of time as is actually observed to be put into circulation, then only one twenty-fifth part of the pressure employed is expended on generating the velocity; the whole of the remaining twenty-four parts out of twenty-five parts, into which the pressure may be conceived to be divided, being expended on the resistances in the air-way, because the squares of 1 and 5, are in the ratio of 1 and 25.

In like manner, if the quantity of air circulated in a given time be found to be only one-fourth of the quantity due to the area and pressure, had there been no resistances in the air-way, it follows that only one-sixteenth part of the pressure is absorbed in expelling the air from the top of the upcast shaft, or extremity of the air-way while the remaining 15-16th parts of the pressure is employed in surmounting the resistances encountered by the air in the mine or air-way. The conclusions stated are true of any single air-tube or passage, whether acting alone or as one

of a connected or ramifying series, as in a mine in which the air is divided by splitting into a number of separate currents; always taking into consideration the entire resistances which any given portion of air encounters, from the moment it enters the downcast shaft through the whole of the route taken by it in the passages of the mine, whether before being split, during its being so, or after its re-union with the other currents, to the moment of its being ejected from the top of the upcast shaft; because it is certain that the air will naturally divide itself in such particular proportions over the various passages which are connected together, as to require, in each instance, the same amount of pressure; and this is as true of the air which forms part of any minor, or sub-split, as of that which never leaves the main splits of air, the air in every instance naturally following the route offering least resistance to its passage, and thus filling each passage with air of that particular velocity which will raise its resistance to the same amount as that of each of the other routes in the same mine or system of ventilation. When, however, from the variations in the temperature of the air circulating, and differences in the ascents and descents of the air-ways, there happens to be a greater or less power, added to or taken from the general ventilating power, in some routes than in others, this law will manifestly be found to obtain only when the necessary addition or reduction of power required for each route is made to take a part in the calculation; the quantity of air circulating in each route being directly proportional, all other things being alike, to the square root of the actual pressure expended on causing it to circulate; including, in estimating such pressure, the effects of the natural pressure in each particular route, arising from the temperature and density of the air in the ascending parts, differing from those of the air in the descending parts; and since such natural pressure may differ, not only in amount but even in the direction in which it operates in one route of any mine, from that operating in any other route, it follows that the actual pressure operating in the different routes or splits of air in the same mine, and at the same time, may differ from each other.

The quantity of air circulating in each route, however, will further be inversely proportional to the specific resistance of such route, depending upon its length, the area and perimeter of its section, the nature of the material of which its internal surface is composed, &c., so that the quantities of air in the different routes of the same mine may, by varying these conditions, come to bear any proportion whatever to each other.

(21.) From the quantities of air being proportional to the square roots

of the pressures employed, other things being constant, we could readily calculate the quantity of air due to any pressure, when we had observed that arising from any other pressure in the same mine or air-way; but it would be a tedious operation to ascertain the actual amount of pressure employed, when the air-ways had many ascending and descending parts traversed by air of different temperatures or densities; and these natural pressures could not be neglected when they happened to bear any considerable proportion to the artificial pressure employed; and they would involve the necessity of making a distinct calculation for each of the splits, and even for each of the minor or sub-splits of air, when the amounts of natural ventilation in such splits differed from each other.

Here, however, we will investigate the case of a mine, in which either the whole of the workings are situated in the same horizontal plane, or, on the other hand, in which the amounts of pressure arising from the natural causes alluded to, happen to be of the same amount, and all operating in the same direction, relative to that of the currents of air traversing them in each of the splits and minor or sub-splits of air; in which case the ventilating pressure may be regarded as being the same in each of the splits of air; and the formulæ and results arising may be considered as approximating nearer to the truth, in proportion as these conditions are less departed from, in mines where they do not fully obtain; and as the amount of artificial ventilating pressure employed bears a greater proportion to any such natural pressure arising in the air-ways from the causes stated.

(22.) In the case of furnace ventilation, if we presume the upcast shaft to have its top and bottom, respectively, situated in the same horizontal planes as the top and bottom of the downcast shaft; and suppose, in the first place, that both shafts are filled with air of the same temperature, then, on heating the air in the upcast shaft, the expansion of the air would drive a portion of it out at the top of the shaft, and the weight of this expelled air would operate as if divided equally over the area in producing ventilation, because the weight of the air in the downcast shaft would remain the same as before, and being no longer opposed or counterbalanced by an equal pressure of air on each unit of surface in the upcast shaft, the entire column of air in the downcast shaft, air-ways, and upcast shaft would be put into motion.

Experiments (2) on the expansion of air by heat lead to the conclusion that if any given volume of air, under a constant pressure and at zero of Fahrenheit's scale of temperature, be conceived to be divided into 459

equal parts, such air will increase in volume to the extent of one of such parts by the addition of each degree of temperature; so that the volume assumed by it will always be proportional to $459+t^{\circ}$, for all the values of t°, which represents the temperature of the air.

Hence if the air in the upcast shaft be considered to have the same temperature as that in the downcast shaft, represented by t, and then to be heated to any other temperature T, it follows that the length of the column of air of the same area of the upcast shaft, would, by the change of temperature from t to T, be altered in the ratio of $459+t$ to $459+T$, inasmuch as any given volume of air would be increased in that proportion. If by d we represent the depth of the upcast shaft in feet, and by H' the length of the column of heated air at T, expelled from the top of the shaft by heating from t to T, also expressed in feet, we obtain the proportion—

$$\text{As } 459+t : 459+T :: d : d+H'$$

And hence the height of the column of heated air, of the area of the upcast shaft, which is capable by its weight of producing the ventilating pressure arising from the heat imparted is

$$H' = d\left(\frac{T-t}{459+t}\right) \ldots\ldots\ldots\ldots\ldots\ldots [20]$$

but since, in the case of mines ventilated by furnaces, the weight of the column of expelled air would be less in the case of a high upcast temperature, than it would be for the same length of expelled column, in a shaft of greater depth with a lower temperature; and since the present object is to obtain general formulæ, for comparing one amount of ventilation and its accompanying conditions with a different ventilation and accompanying conditions, without, to too great an extent, complicating the formulæ, by an affectation of an over nice precision, we shall omit making any allowance for the difference of resistance arising from the difference of expansion in the air, in the upcast shaft, when two different temperatures are compared; in general, the air in its entire route will have a temperature more nearly corresponding to that which exists in the downcast, than in the upcast shaft; and hence we shall reduce the height of the column of air, due to the ventilating pressure, to the standard density due to the temperature in the downcast shaft t; calling the height of the air column of such density H, we have the proportion

$$\text{as } 459+T : 459+t :: H' : H$$

and hence

$$H = H'\left(\frac{459+t}{459+T}\right) \ldots\ldots\ldots\ldots\ldots\ldots [21]$$

and by substituting in this last equation the value of H′ in [20], and reducing, we obtain

$$H = d\left(\frac{T-t}{459+T}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots [22]$$

(23.) In general the length of air column, or the pressure per unit of surface, due to the final velocity with which the air is expelled from the top of the upcast shaft, may be regarded as sensibly the same as that which would be required to generate the final velocity, which would have existed, if the air on its expulsion from the top of the upcast shaft had a temperature T of the same amount as the average temperature in the upcast shaft; seeing that any slight reduction in volume and velocity, arising from the cooling and contraction of the air, after passing the point in the upcast shaft where the average temperature actually prevails, will have its tendency to reduce the pressure required for its expulsion from the top of the shaft, counteracted, to some extent, by the greater density of the expelled air; and hence, for the sake of simplicity, it is intended to treat the pressure due to the expulsion of the air, as being the same as it would have been, had the air retained the average upcast temperature up to the moment of its expulsion from the top of the shaft.

Now by [10]

$$h' = \frac{V'^2}{231{,}600}$$

h′ being the height in feet of air column, of the same density as the flowing air, due to the mere generation of its velocity; which is represented by V′ in feet per minute; and if by Q′ we denote the cubic feet of air (of the volume due to the average temperature of the upcast shaft) per minute; by Q, the same air expressed in volume of cubic feet, due to the temperature of the downcast shaft t; and by A the area, in feet, of the top of the upcast shaft, we obtain

$$V' = \frac{Q'}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [23]$$

and by substituting this value of V′, in [10], we obtain

$$h' = \frac{Q'^2}{231{,}600\ A^2}$$

And since the volume of air at the temperature T of the upcast shaft is to the volume assumed by the same air at the temperature t, of the downcast shaft, in the ratio of 459 + T to 459 + t, we have

$$Q' = Q\left(\frac{459+T}{459+t}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [24]$$

and therefore

$$h' = \frac{Q^2 (459+T)^2}{231{,}600\ A^2\ (459+t)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots [25]$$

but if we represent by h the height in feet of air column (of the density due to the temperature t of the downcast shaft), required for the mere expulsion of the air; since h must be less than h′ in the ratio of 459+T to 459+t, we obtain

$$h = \frac{Q^2\ (459+T)}{231{,}600\ A^2\ (459+t)} \quad \ldots\ldots\ldots\ldots\ldots\ldots [26]$$

now since [22] the entire ventilating column of air at t, the temperature of the downcast shaft, is expressed by $H = d\left(\frac{T-t}{459+T}\right)$; and since by [26]

as above $h = \frac{Q^2\ (459+T)}{231{,}600\ A^2\ (459+t)}$ represents the portion of such column employed in generating the velocity of expulsion of the air from the top of the upcast shaft, it follows that the remainder of the column, or

$$H-h = d\left(\frac{T-t}{459+T}\right) - \frac{Q^2\ (459+T)}{231{,}600\ A^2\ (459+t)} \quad \ldots\ldots\ldots\ldots [27]$$

represents the height of such column required to overcome the various resistances encountered by the air in the shafts and air ways of the mine.

(24.) This last formula [27], furnishes the means of calculating the amount of what has recently been termed the "drag" of a mine. It should however be borne in mind that this drag or resistance will, supposing the temperature of the air and the conditions of the air ways to remain unaltered, vary in the ratio of the square of the velocity of the air over any given section; or what is the same, as the square of the quantity of air circulating per minute; so that if we would compare the drag or resistance of one mine with that of another, or of the same mine under varied conditions, we must calculate or reduce each to some particular quantity of air in circulation per minute, assumed as a standard.

(25.) By means of formulæ [22] and [26] we may ascertain the proportions of ventilating pressure absorbed in any mine in the generation of the final velocity of the air with that required to overcome the drag of the mine, and so determine the loss of air arising from the resistances. As examples, let us take the cases of Hetton and Tyne Main Collieries, as given by Mr. Wood, the president, in his communication to this In-

stitute in December, 1852, and February, 1853, furnace ventilation being in existence in each case, as below:—

	Hetton.	Tyne Main.
Area of upcast shaft, in superficial feet	153	50·257
Depth of do., in lineal feet	900	672
Average temperature of upcast shaft	211°	262°
Average do. of downcast shaft	43°·5	44°
Cubic feet of air per minute	225,176	102,503

In the case of Hetton Colliery the entire head of cool air column, of the density due to the temperature of the downcast shaft employed in the production of ventilation, is, by [22],

$$H = d\left(\frac{T-t}{459+T}\right) = \frac{900\ (211-43.5)}{459+211} = 225 \text{ feet.}$$

The portion of the above ventilating column expended, in this instance, on the expulsion of the air from the top of the upcast shaft, is, by [26],

$$h = \frac{Q^2\ (459+T)}{231{,}600\ A^2\ (459+t)} = \frac{225{,}176^2\ (459+211)}{231{,}600 \times 153^2\ (459+43{\cdot}5)} = 13{\cdot}6 \text{ feet.}$$

that is, 13·6 feet of air, of the density due to the temperature of the downcast shaft, t, would produce the pressure required to generate the final velocity with which the air left the top of the upcast shaft; and therefore this portion of the ventilating column is carried off, so to speak, as momentum in the air leaving the top of the upcast shaft, and is lost to the resistances or drag in the shafts and workings of the mine, which have therefore to be overcome by the remaining part of the ventilating column, which will be (225—13·6)=211·4 feet of vertical column of air of the density due to t.

In this case, therefore, only about 1-16th part of the ventilating pressure is expended on the velocity or motion of the air, while the remaining 15-16th parts of such pressure is expended on overcoming the drag or resistances of the shafts and workings; and since it appears, by the laws recited in Chap. I. that the quantities of air circulating in the same mine are, *cæteris paribus*, proportional to the square roots of the pressures per unit of surface by which they are put into circulation, it follows that only $\sqrt{\frac{1}{16}}$, or 1-4th of the quantity of air circulates, which would have circulated had there been no drag or resistances in the shafts and workings; and if it were possible to remove those resistances, the quantity of air put into circulation by the same pressure would gradually increase in amount as they were reduced; but in this mine, with the *same* pressure, could never exceed four times the quantity—225,176, or 900,704 cubic

feet per minute; because the whole of the pressure, or 225 feet of air column, would then be required to generate the velocity with which the air would leave the upcast shaft.

It is highly probable that a smaller proportion than even 6 per cent. of the ventilating pressure, as in this case, will, in other less effectually ventilated mines, be employed in creating the final velocity, more particularly in cases where the upcast shaft is of greater area in proportion to the extent of the galleries requiring ventilation.

(26.) In the case of Tyne Main Colliery, the entire ventilating column is,

$$H = d\left(\frac{T-t}{459+T}\right) = 672\left(\frac{262-44}{459+262}\right) = 203{\cdot}2 \text{ feet,}$$

or about .3 of the depth of the upcast shaft, even a higher proportion than in the case of Hetton, both being exceedingly hot upcast shafts at the times of observation.

The portion of the ventilating column finally expended on the mere expulsion of the air from the top of the upcast shaft at Tyne Main Colliery is,

$$h = \frac{Q^2\,(459+T)}{231{,}600\ A^2\,(459+t)} = \frac{102{,}503^2\,(459+262)}{231{,}600 \times 50{\cdot}257^2\,(459+44)} = 25{\cdot}7 \text{ feet}$$

being slightly more than 1-8th of the entire ventilating head of cool air or pressure employed in ventilation; so that, in this instance $\sqrt{\frac{1}{8}}$, or rather more than 1-3rd of the air circulates, which would arise from the entire pressure, if there were no resistances to be overcome; about 12½ per cent. of the entire ventilating pressure being employed in the generation of the velocity of expulsion, and the remaining 87½ per cent. being absorbed by the resistances in the shafts and air-ways.

(27.) From a published statement relative to Haswell Colliery, we have

The area of the upcast shaft, in feet	58
Depth of the upcast cast shaft, in lineal feet	936
Average upcast temperature.....	165°
Downcast shaft temperature.....	62°
Cubic feet of air, per minute	94,900

We have, for the entire ventilating column of air, at 62°, in this instance,

$$H = d\left(\frac{T-t}{459+T}\right) = 936\left(\frac{165-62}{459+165}\right) = 154{\cdot}5 \text{ feet,}$$

being rather more than 1-6th of the depth of the upcast shaft; the air-column, of 62°, due to the upcast shaft velocity, in this case, is,

$$h = \frac{Q^2\,(459+T)}{231{,}600\,A^2(459+t)} = \frac{94{,}900^2\,(459+165)}{231{,}600 \times 58^2\,(459+62)} = 13{\cdot}84 \text{ feet.}$$

So that rather less than 1-11th part of the ventilating pressure is expended on the velocity of expulsion, or carried off as momentum by the air leaving the top of the upcast shaft; the remaining part, or rather more than 10-11ths of the entire pressure being employed on overcoming the resistances encountered by the air in the mine and shafts; the quantity of air circulating being to that which would have been expelled from the upcast area, had there been no resistances, in the ratio of $\sqrt{13{\cdot}84}$ to $\sqrt{154{\cdot}5}$, or of 3·72 to 12·43, or about 30 per cent. of the latter quantity.

(28.) For the sake of instituting a comparison between the resistances which would be encountered by equal amounts of air in each of the three cases named, Hetton, Tyne Main, and Haswell Collieries, we have

	Hetton.	Tyne Mn.	Hasw.
Temperature of downcast shafts, assumed as that of the head of air-column	43°·5	44°	62°
Height of air-column employed on the resistances and velocity	225	203·2	154·5
Air-column due to velocity, only.....	13·6	25·7	13·84
Air-column due to resistances.....	211·4	177·5	140·66
Air circulating.....	225,176	102,503	94,900

Reducing the heads of air-column to a standard temperature of, say 62°, the heights due to the resistances of the shafts and mines become 219·2 for Hetton Colliery, 183·8 for Tyne Main Colliery, and 140·66 for Haswell Colliery. The pressures expended on the resistances being proportional to these quantities, we have now to find the pressure required to overcome the resistances in each case, on the presumption of a given and equal quantity of air circulating in each of the mines, in order to be able to compare their respective amounts of drag; and, since the resistances are proportional to the squares of the quantities circulating in a given time, in the same mine, if we assume 1000 feet per minute as the standard for comparison, we obtain for Hetton Colliery,

$$\text{As } 225{,}126^2 : 219{\cdot}2 :: 1000^2 : {\cdot}004325;$$

for Tyne Main Colliery,

$$\text{As } 102{,}503^2 : 183{\cdot}8 :: 1000^2 : {\cdot}01748;$$

and for Haswell Colliery,

$$\text{As } 94{,}900^2 : 140{\cdot}66 :: 1000^2 : {\cdot}01606.$$

Hence the head of air column due to the resistances in the shafts and workings of Hetton colliery would have been ·004325 of a foot, when only 1,000 cubic feet of air per minute circulated:—·01748 of a foot for the circulation of the same amount at Tyne Main colliery, and ·01606 of

a foot for the circulation of the same quantity at the Haswell colliery, the two latter cases presenting, in fact, each about four times the amount of the resistances existing at Hetton colliery. From this, it would appear that if it were practicable and desirable to reduce the resistances in the Tyne Main and the Haswell collieries by further splitting the air, or otherwise, to the same value as those at the Hetton colliery at the time of the observation, an enormous increase in the gross quantities of air circulating in these collieries would be the effect.

(29.) The general law of the quantities being proportional to the square roots of the pressures will enable us to ascertain the quantity of air which would circulate in a mine at any assumed average upcast temperature, provided we have first ascertained the quantity put into circulation by an observed average upcast temperature in the same mine.

Thus, if the quantity of air observed to circulate per minute be Q, when the downcast temperature is t, and the average upcast shaft temperature is T; and if d be the depth of the pit used as an upcast, then by [22], the column of air at t, causing the ventilation, is

$$H = d\left(\frac{T-t}{459+T}\right)$$

And if it be required to calculate the quantity of air Q, which would circulate through the same unaltered mine by altering the average upcast shaft temperature to T, and presuming the downcast shaft temperature to remain at t; then since $d\left(\frac{T-t}{459+T}\right)$ will be the ventilating pressure due to the new temperature, expressed in height of air column at t as before; and since the quantities Q and Q are respectively proportional to the square roots of their corresponding pressures $d\left(\frac{T-t}{459+T}\right)$ and $d\left(\frac{T-t}{459+T}\right)$ we obtain the proportion,

$$\text{As } Q : Q :: \sqrt{d\left(\frac{T-t}{459+T}\right)} : \sqrt{d\left(\frac{T-t}{459+T}\right)}$$

and hence the equitation

$$Q = Q\sqrt{\frac{\frac{T-t}{459+T}}{\frac{T-t}{459+T}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [28]$$

which may be expressed thus—

$$Q = Q\sqrt{\frac{(459+T)\ (T-t)}{(459+T)\ (T-t)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [29]$$

from whence results the following formulæ for determining the upcast temperature T, and the ventilating pressure or head of air column required to put the quantity Q in circulation, provided we have first observed the quantity Q put into circulation by an observed upcast average temperature T; representing such head of air column so required to cause the quantity Q to circulate by $H = d\left(\frac{T-t}{459+T}\right)$; viz:—

$$T = \frac{tQ^2(459+T)+459\,Q^2(T-t)}{Q^2(459+T)-Q^2(T-t)} \quad \ldots\ldots\ldots\ldots\ldots\ldots [30]$$

and

$$H = \frac{Q^2 d(T-t)}{Q^2(459+T)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (31)$$

As an example illustrating the application of these formulæ let us take the case of Haswell colliery, already alluded to, where the average upcast temperature, observed to create a ventilation of 94,900 cubic feet per minute, was 165°, when the downcast shaft temperature was 62°, and let it be required to determine the quantity of air which would be put into circulation by raising the average upcast shaft temperature to the high temperature of 369°8. Taking the formula [29], and having Q=94,900, T=165°, t=62°, and T=369°·8, gives

$$Q = 94{,}900\sqrt{\frac{(459+165)\,(369^\circ\cdot 8-62)}{(459+369^\circ\cdot 8)\,(165-62)}} = 142{,}350 \text{ cubic}$$

feet per minute, as the quantity due to the average upcast temperature of 369°·8; shewing that an increase of nearly 200 per cent. in the excess of the upcast over the downcast shaft temperature only creates an increase of about 50 per cent. in the quantity of air circulating in a given time.

Had it been required to find, by calculation, the temperature of the upcast shaft, which would produce a ventilation of 142,350 cubic feet per minute, after observing that 94,900 cubic feet per minute resulted from an upcast temperature of 165°, in the same time, where the downcast temperature is taken at 62°; then, by [30], we should have had

$$T = \frac{62 \times 94900^2\,(459+165) + 459 \times 142350^2\,(165-62)}{94900^2\,(459+165) - 142350^2\,(165-62)} = 369^\circ\cdot 8,$$

as the average upcast temperature required, showing the mutual agreement of the formulæ [29] and [30].

Again, when the temperature and corresponding ventilation or quantity of air are given, and it is required to calculate the ventilating pressure or height of an air-column due to any other amount of ventilation in the same mine, then, by [31]

$$H = \frac{142350^2 \times 936\,(165-62)}{94900^2\,(459+165)} = 347\cdot 6 \text{ lineal feet}$$

height of air-column due to the ventilation of 142,350 cubic feet of air per minute in the case of Haswell, as already alluded to; so that, whilst a ventilating column of 154·5 feet high put 94,900 cubic feet of air per minute into circulation, it would, in the same mine, require a column 347·6 feet high, of the same density, to put 142,350 cubic feet per minute into circulation—showing how slowly the quantity of air is increased, as compared with the rate of increase of ventilating pressure employed, being an increase of nearly 125 per cent. in the pressure to produce only about 50 per cent. increase in the amount of ventilation, the square root of the pressure increasing as rapidly as the quantity of air put into circulation increases.

When several calculations are to be performed, the operations may be shortened by finding a constant C, for any mine, by first observing a series of corresponding values of Q, T and t, and making

$$C = Q\sqrt{\frac{459+T}{T-t}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [32]$$

For, on substituting this value of $Q\sqrt{\frac{459+T}{T-t}}$ in [29] we get

$$Q = C\sqrt{\frac{T-t}{459+T}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [33]$$

And, by a similar substitution in [30], there results

$$T \quad \frac{459\,Q^2 + C^2 t}{C^2 - Q^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [34]$$

The value of the constant C, as suited to any mine, can readily be found by taking simultaneous values of Q, T, and t, and substituting them in [32]; in the case of Haswell, which has been taken for a previous example, Q = 94,900; T = 165°, and t = 62°, and, by [32] in this instance,

$$C = 94{,}900\sqrt{\frac{459+165}{165-62}} = 233{,}588.$$

By applying [33] to find the quantity of air due to an unusually high upcast temperature, as before, 369°·8,

$$Q = 233{,}588\sqrt{\frac{369{\cdot}8-62}{459+369{\cdot}8}} = 142{,}350 \text{ cubic feet,}$$

as before found. And, in the same instance, by the application of [34], to find the temperature due to the quantity 142,350 cubic feet of air per minute,

$$T = \frac{459 \times 142{,}350^2 + 233{,}588^2 \times 62}{233{,}588^2 - 142{,}350^2} = 369^\circ{\cdot}8;$$

shewing the agreement between [29] and [33], and also between [30] and [34] respectively.

CHAPTER IV.

On the consumption of fuel by ventilating furnaces, and the method of determining the comparative economy of different modes of ventilation.

(30.) In order to determine the comparative economy of fuel by different modes of producing ventilation, it will be necessary to ascertain what would be the consumption of fuel by each mode to effect a fixed or standard amount of ventilation in one and the same mine; and when it is not convenient to do this by experiment, it becomes necessary to ascertain by calculation what would have been the consumption of fuel by each mode had they been so applied; taking as data the results of their application, under different circumstances, or at different mines.

We proceed to investigate formulæ, which may serve to make such comparisons.

Let F = lbs. of coal consumed per minute.

q = number of units of heat given out by each lb. of coal; that is to say, = the number of lbs. of water which each lb. of coal will, by its combustion, raise through 1° of temperature, depending on the quality of the coal.

Q = the corresponding quantity of air put into circulation each minute, reckoned in cubic feet.

w = the weight, in lbs. avoirdupois, of a cubic foot of the air of the density at which Q is determined.

r = the temperature of the return air, before being influenced by the heat of the furnace.

t = the temperature of the downcast shaft, taken where the average heat prevails, if it is not uniform.

T = The average temperature of the upcast shaft.

·2669 = The specific heat of air, when that of water is assumed at unity as a standard; that is to say = the quantity of heat required to raise 1 lb. of air, through the same number of degrees of temperature, which an unit of heat would raise 1 lb. of water through.

Let F = lbs. of coal required to be consumed per minute, to cause a new quantity of air, Q, to circulate through the same mine, when T is taken to represent the corresponding average upcast temperature.

In the case of ventilation by furnace action, the increase of temperature which would be imparted to the air by the fuel would evidently be (if there were no loss by cooling) expressed by

$$\frac{Fq}{\cdot 2669\ Qw} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [35]$$

The real excess of temperature in the upcast shaft over that in the downcast shaft, if there were no loss by cooling, would be

$$\frac{Fq}{\cdot 2669\ Qw} + r - t \ldots\ldots\ldots\ldots\ldots\ldots [36]$$

And when the average prevailing temperature of the upcast shaft is deducted from that which would have prevailed had there been no loss by cooling, the result,

$$\frac{Fq}{\cdot 2669\ Qw} + r - T \ldots\ldots\ldots\ldots\ldots\ldots [37]$$

is the loss of temperature by cooling, after passing the furnace, and before reaching the point where the average temperature, T, prevails in the upcast shaft.

(31.) According to Petit and Dulong, the velocity of cooling, or, in other words, the reduction of temperature which a heated body undergoes in an unit of time, supposing the excess of temperature of the heated body, over that of the medium to which it is exposed, to remain constant, and equal to $T - t$, by taking such unit of time as indefinitely small; calling such velocity of cooling v, is

$$v = m\,(1{\cdot}0077^{(T-t)} - 1) + n\,(T-t)^{1{\cdot}233} \ldots\ldots\ldots\ldots [38]$$

That part of the velocity of cooling represented by $m\,(1{\cdot}0077^{(T-t)} - 1)$, being due to radiation alone; and the remaining part, represented by $n\,(T-t)^{1{\cdot}233}$, being due to the contact of the gaseous medium to which the cooling body is exposed.

The coefficient m, depending for its value upon the nature and extent of the surface of the heated body; while the value of n depends upon the nature and pressure of the surrounding gaseous medium to which the cooling body is exposed, and the extent of surface exposed to it by the body.

The complexity of this expression is such as to render it almost inad-

missable into any but very particular calculations, and for the present object it would perhaps be useless to attempt its introduction, inasmuch as it would probably prevent the formulæ being made use of in cases where more simple formulæ, although mere approximations, would be employed, as being less troublesome.

(32.) We shall probably obtain a tolerable degree of approximation to the truth, if we presume that the reduction of temperature by the cooling of the air, in ascending any upcast shaft, is directly proportional to the prevailing average excess of temperature in the upcast shaft, over the temperature of the downcast shaft, and to the length of time which the air is exposed to the cooling influence of the shaft walls.*

Now, since the time of exposure of the air to the cooling influence of the shaft, just referred to, is, in the same shaft, always inversely proportional to the quantity of air circulating in a given time, the assumption we have adopted leads to the conclusion that the loss of temperature by cooling, after passing the furnace, will, in the same shaft, be proportional to $\frac{T - t}{Q}$; so that we may adopt a constant l, suited to any shaft, of such value, that

$$l \frac{T - t}{Q} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots [39]$$

will express the actual loss of temperature, whatever may be the values of the variables T, t, and Q; and hence [37]

$$l \frac{T-t}{Q} = \frac{Fq}{\cdot 2669\ Qw} + r - T$$

so that by observing any corresponding values of F, Q, T, t, q, w, and r, in any shaft, we can find l; for, by the above,

$$l = \frac{Q}{T-t} \left\{ \frac{Fq}{\cdot 2669\ Qw} + r - T \right\} \ldots\ldots\ldots [40]$$

* It is probable that this assumption is nearly correct, because, according to Newton, if we let—for approximate rules—

A = initial temperature of a heated body;
T = its temperature after the time t;
a = a constant coefficient;
V = the velocity of cooling which will occur during the unit of time, for an excess T of temperature of the body over that of the surrounding medium; and supposing this excess to remain constant, we have the relations

$$\text{Log. } T = \text{Log. } A - \frac{a\,t}{2 \cdot 30}; \text{ and } V = a\,T.$$

By the former we can find the temperature T, after the time t, when we know the value of a, which depends on the weight of the body, and the extent and nature of its envelope or containing vessel, when it is a liquid, which can be determined by a single experiment. The second gives the velocity of cooling, when we know the excess of temperature of the body over that of the medium to which it is exposed.

And the difference, found by deducting the loss by cooling, $l\frac{T-t}{Q}$, from the excess of temperature [36], which would have prevailed, if there had been no cooling, will give the prevailing excess of temperature, as due to the assumed consumption of fuel F, and its corresponding air Q; or

$$T-t = \frac{Fq}{\cdot 2669\ Qw} + r - t - l\frac{T-t}{Q} \quad \ldots\ldots\ldots\ldots\ldots [41]$$

and hence

$$F = \frac{\cdot 2669\ w}{q}\left\{Q\ (T-r) + l\ (T-t)\right\} \quad \ldots\ldots\ldots\ldots\ldots [42]$$

in which equation the value of $T-t$ can first be determined from [30], or [34], as due to the quantity of air Q; by means of any observed corresponding values of T, t, and Q in the same shaft: and from this equation [42] itself, the quantity of fuel F, required to be consumed per minute, to cause the assumed quantity of air Q, to circulate in the same mine, can be found.

These formulæ, as already stated, are based upon the assumption of the loss of temperature by cooling, being proportional to the prevailing excess of the temperature of the upcast, over that of the downcast air; and, inversely, to the quantity of cool air circulating in a given time: it is, however, probable that the loss by cooling increases in a ratio somewhat higher than that of the simple excess of temperature; and, in fact, the time of the air being exposed to the walls of the shaft, will not be precisely inversely proportional to the cool air circulating, but rather to the expanded volume of heated air passing up the shaft in a given time, considerations indicating that the formulæ just given, are not to be regarded as affording more than near approximations to the truth, but as they may be serviceable in making comparisons and calculations on the subject, and may even lead to more simple and trustworthy rules, it has been considered proper to present them.

[33]. Before applying the preceding formulæ to examples, it will be proper to give rules for finding the weight, in lbs. avoirdupoise, of a cubic foot of air, or the value of w. Dr. Prout determined the weight of dry air at the temperature of 60° Fahrenheit, and under a pressure of 30 inches of mercury, to be 535·882176 troy grains, or ·0765546 lbs. avoirdupoise, per cubic foot; and since the density of air is inversely proportional to the sum of the temperature, and the constant number 459, when the pressure remains constant; and again, directly proportional to the pressure under which it exists, when the temperature is constant; if we

express the temperature of the air by t, and the pressure in inches of mercury (reduced to 60°) by f, we get the proportion,

$$\text{As } \frac{30}{459+60} : \cdot 0765546 :: \frac{f}{459+t} : \frac{1\cdot 3244\ f}{459+t}$$

and hence

$$w = \frac{1\cdot 3244\ f}{459+t} \ldots\ldots\ldots\ldots\ldots\ldots [43]$$

When, however, the air contains any vapour of water, the mixture will be of less density than is due to dry air at the same temperature, because the specific gravity of vapour of water, at the same temperature and pressure as dry air, has been found to be less than that of the air. Taking the average of the various slightly differing statements, as regards the specific gravity of vapour of water, we shall find that it is about ·622, that of air at the same temperature and density being assumed at unity as a standard.

Now, in order to find the weight of a cubic foot of any gas or vapour, we have only to ascertain by [43] the weight of a cubic foot of air at the same temperature and pressure, and multiply the result by the specific gravity of the gas or vapour in question. So that if w′ express the weight of a cubic foot of any gas or vapour, of which the specific gravity is s, we have,

$$w' = \frac{1\cdot 3244\ f}{459+t} \times s \ldots\ldots\ldots\ldots [44]$$

Dalton discovered, that, although evaporation takes place more slowly from the surface of a liquid exposed to air or gas, than in a vacuum, yet any given space will admit the self-same quantity of vapour, whether such space be previously filled with air or gas, or whether it be a perfect vacuum; so that when a vapour is generated within a vessel which does not yield to pressure, if it is previously occupied by air or gas, the vapour generated, and the air or gas coexist throughout the entire extent of the vessel, and each exerts its own pressure or elastic force against the sides of the vessel, just as if the other were not present; and hence, the pressure on each unit of surface becomes equal to the sum of the pressure exerted by the air or gas, and that exerted by the vapour. When there is present an excess of the liquid, which gives off the vapour, evaporation goes on till the pressure and density of the vapour become equal to those which are due to the temperature when the vapour is in a state of saturation, and then it ceases. If, for example, the tension of the air or gas = f, and that of the vapour = f′, the tension or pressure of the mixture will be f + f′.

If, however, the sides of the vessel are perfectly yielding under the outward pressure of f, then the mixed air and vapour expand in the ratio of f to $f + f'$, and thereby the pressure of the mixture is reduced to the original pressure of the air f; and hence, in this state of the mixture the elastic force exerted by the air or gas becomes $\left(\frac{f}{f+f'}\right) f$, and that of the vapour $\left(\frac{f}{f+f'}\right) f'$. Now, since, by expansion, the space has been enlarged, a fresh portion of the liquid is converted into vapour, so as to fill it, with the elasticity f', due to the temperature, giving rise to a further expansion, which, in fact, goes on continuously, till the volume of the mixture, is to the original space, in the ratio of f to $f—f'$; because, after complete expansion under the pressure f, the vapour has its full elasticity f', so that the pressure of the air or gas can only be $f—f'$, in order that their sum may be equal to f, the total pressure; and the space occupied by the air, (and penetrated by the gas also), will be inversely proportional to the elastic force of the air before and after expansion, respectively; or as $f—f'$ is to f.

Now, in order to find the elastic force of the vapour of water, mixed with air, it is merely necessary to introduce a vessel into the mixed air and vapour, and to reduce its temperature, by any of the known means, below that at which some of the vapour begins to condense upon the vessel, or what is called the dew point of temperature, and carefully to note the temperature at which such dew or condensed vapour evaporates, as the temperature of the cold vessel returns towards that of the mixed air and vapour; then the elastic force due to the vapour, contained in such mixture, will be found by a reference to a table of the elastic force of vapour of water, as due to different temperatures when the vapour is saturated; using, in referring to such table, the dew point of temperature, observed as already stated; for the vapour in the air would evidently be saturated vapour at that temperature, seeing that it is partially condensed by the slightest further reduction of temperature—then, having determined thus, the elastic force f', and noted the actual temperature of the mixed air and vapour t, we will have by [39], the weight of vapour in each foot of the mixture. In order to obtain the weight of air in each foot of the mixture, we will only have to deduct the tenison f' of the vapour from the total barometrical pressure, to obtain the actual pressure under which the air exists in the mixture, and by using the pressure so found, as the tension or elastic force, and the actual temperature of the mixture in [43], we obtain the weight of air in each cubic foot. Tredgold has given a

formula, which, being used instead of reference to tables, may be relied upon as giving very accurate results in determining the elastic force of the vapour in the air, in inches of mercury. If t° be the observed dew point then

$$f' = \left(\frac{t^\circ + 100}{177}\right)^6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots [45]$$

(34.) Before returning to the general formulæ an example will here be given of the application of those just mentioned, by which to determine the value of w.

Let it be supposed that in a mixture of air and vapour, at a temperature of 201°, the dew point were noted at 176°, the barometrical pressure being 30 inches, then, in order to determine the weight of air in each cubic foot of space, on referring to Dalton's table hereinafter given, we would find the tension of saturated vapour, at a temperature of 176°, as being 13·92 inches of mercury=f′, and consequently (30—13·92=) 16·08 is the tension of the air with which it is mixed, under the general atmospheric pressure of 30 inches of mercury. Now, by [43] the weight of air only in each cubic foot, is

$$w = \frac{1{\cdot}3244 \times 16{\cdot}08}{459 + 201^\circ} = {\cdot}032267 \text{ lbs. avoirdupoise.}$$

The weight of vapour in each cubic foot of the mixture, by [44], is

$$w' = \frac{1{\cdot}3244 \times 13{\cdot}92}{459 + 201} \times {\cdot}622 = {\cdot}017374 \text{ lbs.}$$

And the weight of a cubic foot of the mixture consequently is ·032,267 + ·017,374=·049,641 lbs. avoirdupoise.

The weight of a cubic foot of dry air, at the same pressure and temperature as those of the mixture, would, by [43], have been, $\frac{1{\cdot}3244 \times 30}{459 + 201} = {\cdot}06202$ lbs., showing that the mixture is lighter than dry air.

The tension of vapour of water at 176°, as given by Tredgold's formula, is 14·37, which, it will be seen, agrees very nearly with Dalton's table. The use of the formula in this case being as follows:—

176° + 100 = 276, the log. of which is	2·4409091
177, a constant number, the log. being	2·2479733
Difference	0·1929358
Index, or constant multiplier	6
14·37= the natural number of the product	1·1576148

(35.) When any large proportion of vapour of water is present in air, instead of using ·2669, the specific heat of air, and w as determined by [43], in order to obtain the unities of heat required to raise a cubic foot through a degree of temperature, it will be necessary to find the weight of air and the weight of vapour in each cubic foot of space, as just shown, and to multiply the weight of air by ·2669, and that of the vapour by ·847—the specific heats of dry air and of vapour of water respectively,—and to make use of the sum of the products in lieu of using ·2669 w, in [35], [36], [37], [40], [41], or [42], or any others into which these quantities enter, as they can only apply to dry air, although where the vapour is of low tension no great error will arise from taking the formulæ as they stand.

In mines the air is often in a state of saturation with vapour before reaching the furnace, and if we take the tension due to 61° it is ·524=f′; and if the barometer stood at 30 inches, the tension of the air would be 30—·524=29·476; the weight of air in each cubic foot being by [43],

$$w = \frac{1{\cdot}3244 \times 29{\cdot}476}{459 + 61^\circ} = {\cdot}075073 \text{ lbs.}$$

The weight of vapour in each cubic foot being, by [44],

$$w' = \frac{1{\cdot}3244 \times {\cdot}524}{459 + 61^\circ} \times {\cdot}622 = {\cdot}000{,}830 \text{ lbs.}$$

and the weight of a cubic foot of the mixture would be ·075073 + ·000830 = ·075903 lbs., the weight of a cubic foot of dry air being ·076408 lbs., so that the error in weight, when the vapour only has a tension due to 61°, under a pressure of 30 inches, would never exceed about 2-3rds per cent., whatever might be the actual temperature of the mixture, as the air and vapour expand alike. The specific heat of the mixture would require to be taken as

$$\frac{{\cdot}075073 \times {\cdot}2669 + {\cdot}00083 \times {\cdot}847}{{\cdot}076408} = {\cdot}2714,$$

that of dry air being ·2669, so that the error here again would only be $1\frac{3}{4}$ per cent.

(36.) To give an example illustrating the application of the formulæ at the commencement of this Chapter, let it be presumed that in the case of Haswell colliery, as already alluded to, there was burnt 17·3212 lbs. of coal per minute, when 94,900 cubic feet of air was circulating, and that the quality of the coal was such as to give out 13,800 unities of heat per lb. of coal, over and beyond all waste of combustible and other matter in the cinders, soot, and smoke; that is to say, supposing each lb. of coal put into the furnace to give out sufficient heat in combustion, as it

occurred, to raise 13,800 lbs. of water through 1° of temperature, then, by [37], the loss by cooling would be

$$\frac{17{\cdot}3212 \times 13{,}800}{{\cdot}2669 \times 94{,}900 \times {\cdot}07626} + 67^\circ - 165^\circ = 25^\circ{\cdot}75,$$

when the weight w of a cubic foot of air is taken at ·07626 lbs.

And since (165°—62°)=103° was the prevailing excess of temperature, it follows that the initial excess of temperature must have been (103+25·75)=128°·75, and that the loss has been $\left(\frac{25{\cdot}75 \times 100}{128{\cdot}75}\right) = 20$ per cent. of such initial excess, which is equal to $\left(\frac{25{\cdot}75 \times 100}{103}\right) = 25$ per cent. of the prevailing excess of temperature.

In the same case the value of the constant l will be found by the use of [40], to be

$$l = \frac{94900}{165-62} \times 25^\circ{\cdot}75 = 23{,}725.$$

Taking this value of l, and, by [39], we can find the loss by cooling when the larger quantity, or 142,350 cubic feet per minute are circulating; thus,

$$23725 \left(\frac{369^\circ{\cdot}8 - 62^\circ}{142{,}350}\right) = 51^\circ{\cdot}3,$$

it being, in this instance, only 16 2-3ds per cent. of the initial excess of temperature. And although this is a smaller per centage of the initial excess of temperature than was found to prevail when the lesser quantity of air was circulating—owing to the greater quantity of air being a shorter time exposed to the cooling influence of the shaft walls—yet since the actual quantity of air losing the temperature, and also the actual reduction of temperature, are both increased, in the case of the greater circulation of air, we find that the real loss of caloric is very much greater also, it being, in the two cases, proportional to the products 142,350 × 51°·3 and 94,900 × 25°·75, or nearly 3 to 1, although the quantities of air are only in the ratio of about 1½ to 1.

By [42] we find that the consumption of coal required to put 142,350 cubic feet of air per minute into circulation, would be, using [30] or [34] to find $T = 369^\circ{\cdot}8$; $F = \frac{{\cdot}2669 \times {\cdot}07626}{13800} \left\{ 142350 \times (369^\circ{\cdot}8 - 67^\circ) + 23{,}725 \times (369^\circ{\cdot}8 - 62^\circ) \right\} = 74{\cdot}345$ lbs. per minute, being 4·29 times the quantity of coal required to put the lesser quantity, (or about ⅔rds of the quantity,) of air into circulation in the same unaltered mine, in an equal time. Each lb. of coal, when the lesser quantity of air is circulating, therefore, puts $\frac{94900}{17{\cdot}3212} = 5{,}479$ cubic feet of air into circulation; but

so enormous must be the increase in the consumption of fuel, to put $1\frac{1}{2}$ times this quantity of air into circulation, that it will be increased 4·29 times—each lb. of coal then putting only $\frac{142350}{74{\cdot}345} = 1{,}914$ cubic feet of air per minute into circulation, in the same unaltered mine.

The quantity of air put into circulation in a given time, in the same mine, therefore, increases very slowly compared with the necessary accompanying increase of fuel, consumed; there being in fact no increase in the ventilating pressure, where furnace action is employed, produced by that part of the fuel required to heat the additional air up to the original shaft temperature; while the remainder of the additional fuel, only adds to the quantity of air put into circulation, in a ratio proportional to the square root of the entire pressure produced; so that, on the whole, the consumption of fuel required for the production of ventilation, by furnace action, increases in a ratio somewhat higher than even the cube of the quantity of air put into circulation in a given time.

If we now presume that the question had been to determine what the consumption of fuel would have been, in the same instance as that already taken, to produce an upcast shaft average temperature of 369°·8; we should in the first place require to determine the quantity of air Q, which would be put into circulation, in the case in question, by such an upcast temperature; and this could readily be found; for, by [32] we should find the value of $C = 233{,}588$; and then by [33] we should find the value of $Q = 142{,}350$: and then, on substituting these values of T and Q, in [42], we should, as before, have found

$$F = \frac{{\cdot}2669 \times {\cdot}07626}{13800} \left\{ 142350\,(369^{\circ}{\cdot}8 - 67^{\circ}) + 23725\,(369^{\circ}{\cdot}8 - 62) \right\} = 74{\cdot}345 \text{ lbs.}$$

for the consumption of fuel per minute: the value of l, in each instance, being found by [40].

If, however, it had been required to determine by calculation, the quantity of air Q, due to some assumed consumption of fuel F, the case becomes more intricate, requiring the solution of a cubic equation, with very troublesome coefficients; and in preference to this mode, it might be better to assume a value of Q, and by proceeding, as has been indicated, for the case of the quantity of air being given, find out the corresponding consumption of fuel; repeating the process, on the principle of double position, until the actual quantity of air is found, to the degree of nicety considered desirable.

A similar remark will apply to the case of the upcast average tempera-

ture requiring to be determined, when only the consumption of fuel is given, or assumed.

(37.) When ventilation is created by engine power applied through machinery, the consumption of fuel may be taken to be proportional to the power exerted by the same machine. The entire pressure per unit of surface may be taken, as already stated, as being proportional to the square of the volume of air circulating through the workings of the mine, which we will presume to be the same as the volume passing through the machine, for even 5 inches of water pressure is not more than one-eightieth part of the entire pressure of the atmosphere, and on the average, in mines, the expansion or condension will alter the volume of the air, in a machine, only about one-half of this amount, from the average volume of air in the workings.

If A represent the area of the upcast shaft, and Q the cubic feet of air circulating per minute, then will $\frac{Q}{A}$ be the velocity of the air in the shaft in feet per minute; then, if p represent the pressure in lbs. per su perficial foot of shaft area, required to move the air through the mine, we shall have p A for the entire pressure exerted over the total area of the shaft, for this purpose; and consequently $\frac{Q}{A} \times p\,A \div 33000$ will be the horses' power exerted in moving the air up to the mouth of the upcast shaft, which is expressed by $\frac{Q\,p}{33,000}$; reasoning in a similar manner with regard to the power required to draw the air into the ventilating machine, when it acts by propulsion, or to expel the air into the atmosphere, when the machine acts by exhaustion, and calling the area of the opening from the machine to the atmosphere, a, and the pressure required, p′, we shall have the horses' power expended upon this, expressed by $\frac{Qp'}{33,000}$; and consequently, the entire power will be expressed by their sum, or

$$H = \frac{Q\,(p+p')}{33,000} \quad \ldots\ldots\ldots\ldots\ldots\ldots [46]$$

where H is the number of horses' power exerted.

But, since the squares of the quantities are proportional to the pressures per unit of surface, under similar conditions $p+p'$ will be proportional to Q^2, and therefore a constant, c, may be adopted for any given case, of such a value that

$$p+p' = cQ^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots [47]$$

whatever may be the quantity of air circulating, or its corresponding

pressures p and p′, in the same machine, and unaltered mine; by substituting which value of p+p′ in [46], we obtain

$$H = \frac{cQ^3}{33{,}000} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [48]$$

and since c, and 33,000, are both constants in any one case, we perceive that $H \propto Q^3$; and since the power is proportional to the cube of the quantity of air circulating in any given mine, by the same machine, and the consumption of fuel is proportional to the power exerted, it follows that, under the same circumstances, the consumption of fuel by an engine employed in ventilation, will also be proportional to be cube of the quantity of air put into circulation in a given time.

The value of c, as suited to any particular case, where a ventilating machine is already at work, will be found by observing corresponding values of p, p′, and Q; and using the following formula, which is deduced from [47]

$$c = \frac{p+p'}{Q^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots [49]$$

after which, the quantity of air which will be put into circulation in the same case, by any power whatever, may be found by the following formula, arising from [48],

$$Q = \sqrt[3]{\frac{33{,}000\,H}{c}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [50]$$

while the power due to any other assumed quantity of air, can be found by [48] itself.

The consumption of fuel by the engine, expressed in lbs., per horse power, per hour, being denoted by f; and the entire consumption, in lbs. per minute being denoted by F, gives $\frac{fH}{60} = F$; and hence, $H = \frac{F60}{f}$; which value of H being substituted in [46], gives

$$\frac{60\,F}{f} = \frac{Q\,(p+p')}{33{,}000}$$

and in [48], gives

$$\frac{60\,F}{f} = \frac{c\,Q^3}{33{,}000} \quad \ldots\ldots\ldots\ldots\ldots\ldots [51]$$

From whence

$$F = \frac{c\,f}{1{,}980{,}000}\,Q^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots [52]$$

by which the consumption of fuel can be found, whatever may be the quantity of air circulating; and

$$Q = \sqrt[3]{\frac{1{,}980{,}000}{c\ f} F} \quad \ldots\ldots\ldots\ldots\ldots [53]$$

by which the quantity of air due to any consumption of fuel whatever, may be found.

As an example, illustrating the application of these formulæ, let it be required to find the comparative economy of fuel, between the use of ventilating furnaces, and an exhausting ventilating machine, of the description used in the Hartz mines, called the Hartz ventilator, if applied to the case of Haswell Colliery, on the data already given.

When 94,900 cubic feet of air per minute was put into circulation by furnace action, we have presumed the consumption of fuel to have been 17·3212 lbs. of coal per minute, which is probably close upon the real consumption. The head of air column, due to the ventilating pressure, we have determined to be 154·5 feet; and supposing the density of the air to have been .0757 lbs. per foot, the temperature at which the height of the column is calculated being 62°, and the air is presumed to have been nearly saturated with vapour due to that temperature, then the ventilating pressure would be $154{\cdot}5 \times {\cdot}0757 = 11{\cdot}69565$ lbs. per foot, = p in our formula; and if we presume, the pressure required to expel the air from the receiver of the ventilating machine to be 5·30435 lbs. per foot, we should have this, for the value of p′, and $p + p' = 17$ lbs. per foot; and, by [46], the horse power required

$$H = \frac{94{,}900 \times 17}{33{,}000} = 48{\cdot}89$$

By [49] we should have, in this case, the value of

$$c = \frac{17}{94{,}900^3} = .000{,}000{,}001{,}887$$

and if we take the consumption of fuel, by the engine, at 12 lbs. per horse power per hour, we should have, by [52],

$$F = \frac{.000{,}000{,}001{,}887 \times 12}{1{,}980{,}000} \times 94{,}900^3 = 9{\cdot}78 \text{ lb.}$$

for the consumption of fuel per minute by such an engine working the ventilating machine, when 94,900 cubic feet of air per minute was circulating, as compared with the assumed consumption of 17·3212 lbs. of coal per minute by furnace action to create the same amount of ventilation, the pit being 150 fathoms deep. In pits of greater depth the furnace will operate more economically, and in others of less depth its consumption of fuel would be greater, other things being constant.

All the formulæ given in this Chapter are based upon the presumption

of there being no natural sources of ventilating pressure in the mines to which they are applied, and they can only be strictly considered as applying where this is so; at the same time in deep shafts, and where the inclination of the mines is moderate, and a tolerably active ventilation is kept up by artificial means, they will form good approximate rules, although the tops and bottoms of the downcast and upcast shafts do not happen to be situated in the same horizontal planes, and there be some sources of natural ventilation arising from the air in the ascending parts of workings being rather warmer than in descending parts, or the reverse, so long as such causes operate to a small amount in comparison with the applied ventilating power.

In shallow pits, and where mines lie at a considerable degree of inclination to the horizon, particularly when the ventilating power in use is small, the formulæ given will not apply; natural ventilation, in such cases, often forming a large proportion of the whole ventilating power in operation.

CHAPTER V.

On the circulation of air through long galleries or air ways—the benefits of "splitting" the air in mines.

(38.) A perusal of the laws recited in Chapter I. lead to the conclusion that the entire pressure per unit of surface required to overcome the various resistances to the circulation of air in confined passages, will be proportional to the square of the quantity of air circulating per minute, so long as the form, nature, and dimensions of the air ways remain unaltered; because the pressure due to each kind of resistance follows the law of variation just named; and, therefore, the sum of all these pressures must vary in the same proportion.

When, however, the axis of a gallery or air way is not situated in the same horizontal plane, throughout its whole extent, but ascends or descends to different elevations or levels in its course; it becomes necessary to consider the effects of the ascending and descending columns of air in such parts, which will, by their gravitation, necessarily affect the circulation of the air—excepting, indeed, in cases where the effects of the gravitation of the air in the ascending parts are exactly equal to, and so counteract the effects of, gravitation on the descending parts—as any excess of the one over the other will represent a constant pressure, either in favor of, and assisting ventilation; or retarding it, as the case may be; but being invariable in amount, so long as the temperatures of the air remain the same, whatever may be the quantity of air in circulation.

(39.) Again, if the final or exit end of an air way, such as the top of an upcast pit, when we are considering the entire mine as the air way, be situated at a higher level than the initial or entrance end of the air way, (the top of the downcast shaft, under such circumstances;) so that the barometrical compression of the atmosphere is not the same at these two points; it becomes necessary in considering the dynamical state of the

entire system to make allowances for any difference of pressure arising from this cause; which, like the pressures last alluded to (38), remains constant; or may in general be regarded as doing so, in the same mine, whatever may be the quantity of air circulating in a given time.

(40.) It may further be observed that the pressure per unit of surface, due to the generation of any velocity possessed by a current of air, when it first reaches the initial or entrance end of an air way under notice, will act as momentum and assist in propelling the air through the air way; so that it may be regarded as so much ventilating pressure assisting the other sources of ventilating pressure in causing the air to circulate; and, on the other hand, any pressure due to the generation of the final velocity with which the air is ejected from the exit end of the air way under notice, will be carried off as momentum by the ejected air, and will be a constant source of expenditure of ventilating pressure: these pressures, however, are proportional to the square of the quantity of air circulating in a given time in the same mine.

The air, entering the top of a downcast shaft from a state of rest, must not be regarded as reaching the entrance end of the air way with a positive velocity, because, in fact, it starts from a state of repose when we disregard the effects of winds, which we are not here considering—but the pressure due to the generation of the velocity with which the air leaves the top of an upcast pit, or the exit end of an air way or gallery, or any particular portion of an air way under notice, will always require to be considered as a real expenditure of pressure, over and beyond the amount due to the frictional and other resistances, offered by the passage or air way. When, however, we are confining our notice and observations to only some limited portion of an air way, or series of air ways, where the air actually reaches and enters upon such portion with a real velocity, it becomes necessary to consider the effects of momentum, as possessed by the air when it so enters; because the pressure due to the generation of the velocity in question is, in fact, so much pressure assisting any other sources of ventilating pressure in propelling the air through the air way, and finally ejecting it therefrom.

(41.) In order to enter upon the investigation of this part of our subject, let us take a case where we will suppose that the tops of the downcast and upcast pits are situated at the same level, each of the same depth, and that the gravitation of the air in all the ascending parts of the air ways (the shafts only excepted) exactly equals and counteracts the gravitation of the air in all the descending parts of the air ways; under which circumstances no natural ventilation would prevail.

Then, if

D_o=The pressure per superficial foot (expressed in feet of air column, of the density due to the air in the downcast shaft) arising from the air in the downcast shaft, being in fact the depth of the downcast shaft itself in lineal feet.

U_o=The pressure per superficial foot, (also expressed in feet of air column, of the density of the air in the downcast shaft), due to the air in the upcast shaft.

R=The pressure per superficial foot, (also expressed in the same terms as D_o and U_o), required to overcome the frictional resistance offered by the shafts and air-ways when only one cubic foot of air per minute is in circulation.

A=The area in feet of the top of the upcast shaft.

Q=The number of cubic feet of air circulating per minute.

Under the circumstances just supposed, we would have for the entire ventilating pressure employed $D_o - U_o$; and the portion of this pressure employed on overcoming the frictional resistances of the shafts and air-ways would be expressed by Q^2R; the remaining part of the ventilating pressure employed would be expended on the expulsion of the air from the top of the upcast shaft, (presuming that Péclet's experiments are correct in leading to the conclusion that angles and turnings do not increase the resistance of an air-way; or on the other hand that R includes any such resistances, as due to the mine, if they exist), where the velocity would be $\frac{Q}{A}$ expressed in lineal feet per minute, and the pressure due to its generation, as deduced from [10], would be $\frac{Q^2}{231{,}600\ A^2}$; giving, therefore,

$$D_o - U_o = Q^2R + \frac{Q^2}{231{,}600\ A^2} \quad \ldots\ldots\ldots\ldots\ldots [54]$$

which may be reduced to

$$D_o - U_o = Q^2 \left(R + \frac{1}{231{,}600\ A^2}\right) \ldots\ldots\ldots\ldots [55]$$

and gives rise to the equations,

$$Q = \sqrt{\frac{D_o - U_o}{R + \frac{1}{231{,}600\ A^2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [56]$$

and

$$R = \frac{D_o - U_o}{Q^2} - \frac{1}{231{,}600\ A^2} \ldots\ldots\ldots\ldots\ldots [57]$$

And if we presume furnace ventilation to be the means used to cause the air to circulate, by referring to [22] we perceive that,

$$D_o - U_o = d\left\{\frac{T-t}{459+T}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots [58]$$

and, by substitution,

$$Q = \sqrt{\frac{d\left\{\frac{T-t}{459+T}\right\}}{R + \frac{1}{231{,}600\ A^2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [59]$$

and,

$$R = \frac{d\left\{\frac{T-t}{459+T}\right\}}{Q^2} - \frac{1}{231{,}600\ A^2} \quad \ldots\ldots\ldots [60]$$

On comparing equations [59] and [33], it will be seen that they are of the same form, and, in fact, that,

$$C = \sqrt{\frac{d}{R + \frac{1}{231{,}600\ A^2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [61]$$

So that if we had the means of determining the pressure per unit of surface R, required for circulating one cubic foot of air per minute, by measuring the dimensions of the air-ways, contractions, &c., in such a mine; we could, by [61], determine the value of the constant C; and then, by [34] we should be able to determine the upcast temperature required to circulate any quantity of air in the mine; or, by [33], we could find the quantity of air which would be put into circulation in the mine by any assumed upcast shaft temperature, and that without any previous observations on corresponding or simultaneous upcast shaft temperatures and quantities of air.

(42.) To determine the value of R, or the pressure per unit of surface due to the resistances arising from friction, contractions, &c., in a mine, by means of measurements and observations on the resistance offered by different materials, composing the inner surfaces of the air-ways, as due to the circulation of one cubic foot of air per minute, would generally be an extremely troublesome operation, and in extensive mines where the air is subject to great losses by the leakage of stoppings and doors, and often has the chance of passing through galleries and goaves, so filled with fallen stones and other materials as to render them inaccessible, it would be useless to attempt such a task; at the same time, for many purposes other than the ventilation of mines, such as the transmis-

sion of air or gases through pipes, flues, or chimneys, it may be useful to be able to determine in this manner, the pressure in question; and hence we shall not think it a waste of time to give formulæ bearing upon the subject, more particularly as they may, if used in conjunction with other means, to be explained in a future page, be found useful in considering the ventilation of the most extensive and complicated mines.

(43). In order to find the value of R by means of measurements, and observations on the nature of the materials forming the internal walls of an air-way, pipe, or flue, it will be desirable, in the first place, to consider it as divided into such short lengths as may be necessary, in order that the area and perimeter of section, and also the nature and state of the material composing the inner surface may be uniform throughout the entire extent of each division, or, where, from the tapering nature of the air-way, pipe, or flue, this uniformity of section does not extend over any definite distance, other divisions should be made, so that uniformly tapering frustra of cones or pyramids be formed of the tapering portions.

If, then,

L=The length in feet of any such division.

c=The perimeter of the section of the same uniform division, in lineal feet.

A=The area of the section, over the extent of the same division, in superficial feet.

K=The co-efficient of frictional resistance due to the nature of the material forming the internal walls of the air-way, being the pressure required to overcome the frictional resistance offered to the air when moving at the rate of one foot per second, for each superficial foot of rubbing surface exposed to the moving air.

Then, by (5), (6), (7), and (8), we have, for the pressure per unit of surface required to overcome the friction of a cubic foot of air per minute, passing through the division under consideration alone,

$$K \frac{L c}{A^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [62]$$

and since this pressure is proportional to the square of the quantity of air circulating in a given time,

$$K \frac{Q^2 L c}{A^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [63]$$

will be the pressure per unit of surface required to overcome the frictional resistances of the same division, when any other quantity of air, Q, is in circulation through it, per minute.

By applying [62] with different values of K, L, c, and A, as suited to each separate division, we shall successively obtain the amount of pressure

required to overcome the frictional resistances of each of them, as due to one cubic foot of air per minute passing through each.

Referring to (14), and considering that the quantity divided by the area, gives the velocity, we find that the pressure required to overcome the additional resistance arising at each diaphragm or regulator, when only one cubic foot of air per minute is passing, will be expressed by

$$\frac{a}{A}\left\{\frac{\frac{1}{a^2}-\frac{1}{A^2}}{231{,}600}\right\} \ldots\ldots\ldots\ldots\ldots\ldots [64]$$

a being the area of the hole in the diaphragm, and A that of the air-way in feet. A little more than one-half of this amount being, probably, the pressure due to each sudden contraction of the air-way in the direction of the current of air; but, as to which, further experiments appear to be desirable, as also with respect to the above empirical formula, which does not give precisely correct results.

For each conical part of the air-way, the pressure per unit of surface, due to one cubic foot of air per minute passing, will be found by the expression

$$\frac{K\,L\,(m^4-1)}{d\,(m-1)\,m^4\,A^2\,\text{Cos}\,u} \ldots\ldots\ldots\ldots\ldots [65]$$

where L is the length of the frustrum, in feet; A the area in feet of the smaller end of the frustrum; m, the ratio of the greater to the lesser diameter of the frustrum at its extremities; d being the lesser diameter in feet; and u the ratio of the area of the contracted vein to that of the full area of the frustrum, when the conditions are such that a contraction of the flowing vein of air occurs at the end of the frustrum where the air enters it.

But when m exceeds 2 or 3, and the cone is long in proportion to its diameters, we may employ, as sufficiently correct, the expression

$$\frac{K\,L}{d\,(m-1)\,A^2} \ldots\ldots\ldots\ldots\ldots\ldots [66]$$

It results from the fact that the ratio of the perimeter to the area, is the same in a square as its inscribed circle, that the resistance is the same in the two figures alluded to when the velocities are equal; but, for equal quantities of air in a given time, the velocities will be inversely proportional to the areas, and the resistances inversely proportional to the squares of the areas, (being directly proportional to the squares of the velocities,) so that, in order to find the resistance due to one cubic foot of air per minute, passing through a four-sided pyramid, it will only be necessary to employ [65] or [66] to determine the pressure due to a cubic foot of air per minute, in passing through the inscribed cone, and

the pressure so found, on being multiplied by the square of ·7854 or ·6168, will give the pressure required to circulate one cubic foot of air per minute through the four-sided frustrum.

After having, by the means just mentioned, obtained the amount of pressure per foot area, required to overcome the frictional resistance, and the contractions, in each of the divisions or short lengths into which it has been necessary to divide the air-way, it only remains to add the whole of them together to obtain the entire pressure due to such resistances, when one cubic foot of air is circulating through the air-way; and this is, in fact, the value of R in the preceding formulæ; and since the pressure required is proportional to the square of the quantity of air circulating in a given time, when the air way remains unaltered, it follows that Q^2 R will be the pressure per foot area, required to overcome these resistances when the quantity Q is in circulation.

(44.) If the air, instead of being confined to one single pipe, flue, or air way, situated in a horizontal plane, had the option of dividing itself into various splits by following different passages, situated in the same plane, instead of using the value of R, as due to any particular route taken by the air, it would be necessary to find the value of R, as the pressure due to the resistances indicated by it, in an imaginary passage, which should present exactly the same amount of resistances as the joint action of all the united passages would, in fact, present, when considered as aiding each other in transmitting one cubic foot of air per minute; and the value of R so found, could then be used in any of the formula already given, so as to give correct results into whatsoever number of splits the air might be divided.

If, for instance, at any particular part, the air-way divided so as to present two distinct routes to the air, a portion following each of the ways so presented; and if we had found the pressure required to overcome the frictional resistances, contractions, and angles, and to generate the final velocity occurring in one of the routes, by [55], on the presumption of one cubic foot of air per minute passing through it, and represented that pressure by M_1. And if the pressure due to the transmission of one cubic foot of air per minute were found by [55], for the other of the two routes, and represented by M_2— excluding in each case, any pressure due to the parts of the air-way, traversed by the air before reaching, or after leaving the divided passages. If we further represented by M the pressure per unit of surface required to transmit only one cubic foot per minute through the two routes jointly, Q_1 representing the quantity going by the route to which M_1 has reference; and consequently $(1—Q_1)$ going by the route to which M_2 has reference.

The pressures M, M_1, and M_2, in each case, being understood to embrace the pressure due to the generation of any initial velocity which the air may possess on its arrival at the entrance end of the divided air-ways, immediately before being split or divided; as any such pressure, in the form of momentum, actually assists in the transmission of the air through the splits. Then if the air-ways are either situated in the same horizontal plane over their entire length, or, on the other hand, the density of the air is so uniform that the gravitation of the air in the ascents and descents in each particular route exactly counteract each others effects, it follows that the air will naturally so divide itself, between the two routes, that the expenditure of pressure in each instance, including that due to the generation of their respective final velocities, shall be of equal amount, or so that

$$M = Q_1^2 M_1 = (1 - Q_1)^2 M_2 \ldots\ldots\ldots\ldots\ldots\ldots [67]$$

and hence,

$$\text{As } Q_1 : (1 - Q_1) :: \sqrt{M_2} : \sqrt{M_1}$$

and also,

$$\text{As } Q_1 : 1 :: \sqrt{M_2} : \sqrt{M_1} + \sqrt{M_2}$$

and therefore,

$$Q_1 = \frac{\sqrt{M_2}}{\sqrt{M_1} + \sqrt{M_2}} \ldots\ldots\ldots\ldots\ldots\ldots [68]$$

and by substituting this value of Q_1 in [67], we get,

$$M = \frac{M_1 M_2}{M_1 + 2\sqrt{M_1 M_2} + M_2} \ldots\ldots\ldots\ldots\ldots\ldots [69]$$

as the pressure, which is just capable of transmitting one cubic foot of air per minute through an air-way, which, alone, would present equal facilities for the transmission of air with those offered by the two air-ways acting in aid of each other; or, what is the same, the pressure per unit of surface capable of transmitting a cubic foot of air per minute through the two air-ways, considered jointly.

It must here be noticed that M, M_1, and M_2, in the above formulæ, embrace the effects of the initial and final velocities, and so represent the portion of $D_o - U_o$, expended upon the divided parts of the air-ways, when one cubic foot of air per minute only is in circulation (and $Q^2 M$, $Q^2 M_1$, and $Q^2 M_2$ the portion when any quantity, Q, is circulating, as in [55];) and hence have a different signification from R, in that formula; being, in fact, the same as $R + \frac{1}{231{,}600\ A^2}$ in that formula, when the air starts from a state of rest.

(45.) If instead of the air-way being divided into only two, it were, at the same place, divided into any greater number of ways or branches, we could find the joint effect or value of M, as due to the whole of them, on the same principles; for, taking any two of them, we could find, by [69] a value of M as suited to them, acting jointly, one in aid of the other; and then, by adopting M, so found, and substituting it in [69] for M_1, and using M_3, as the pressure due to one cubic foot per minute being sent through the third route, instead of M_2 in the same formula, we would find the pressure required to send a cubic foot of air per minute through such three routes, when acting jointly; and so on, for any number of routes into which the air-way might diverge.

(46.) Although, in order to arrive at the quantity of air which will pursue each separate route, where the air is split, it has been necessary to consider the entire resistance, including that due to the final velocity at the end of each split, and also to include in the force or pressure employed that which is due to the velocity with which the air reaches the point where it is split or divided, it will not be necessary to consider these pressures at the commencement and termination of each of the minor, or ordinary divisions into which the air-way may be considered as divided, for finding the pressure due to the whole air-way, because the final velocity of the air at the end of each of such divisions will necessarily be the initial velocity of the succeeding division, and so its effects would be continually counteracted in adding the total resistances together, to obtain the resistance of the entire passage or air-way.

(47.) In order to find the quantities of air Q_1, Q_2, Q_3, &c., which would pursue particular routes into which an air-way may be divided, the specific resistances of which are M_1, M_2, M_3, &c., when M is the specific resistance, found by the rules already given, as due to the joint and united operation of the whole of them; when the entire quantity of air transmitted through them is Q (always presuming the point where they divide and re-unite, each to the parent current, is the same) and they are not affected by the gravitation of the air in the ascending and descending parts of the routes, we have only to consider that

$$Q_1^2 M_1 = Q_2^2 M_2 = Q_3^2 M_3, \text{ \&c., and that, therefore,}$$

$$Q_1 \sqrt{M_1} = Q_2 \sqrt{M_2} = Q_3 \sqrt{M_3} = Q \sqrt{M} \text{ and hence}$$

$$Q_1 = Q \sqrt{\frac{M}{M_1}}\,;\ Q_2 = Q \sqrt{\frac{M}{M_2}}\,;\ Q_3 = Q \sqrt{\frac{M}{M_3}}\,;\ \text{\&c.;} \ldots [70]$$

for any number of routes so circumstanced.

If, on the other hand, we had determined the specific resistance to which the joint action of any number of routes so situated are equivalent, to be M, and had observed the quantities of air flowing through the various routes to be Q_1, Q_2, Q_3, &c., we could thereby determine the specific resistance of each particular route, because, by [70], we obtain,

$$M_1 = \left(\frac{Q}{Q_1}\right)^2 M;\ M_2 = \left(\frac{Q}{Q_2}\right)^2 M;\ M_3 = \left(\frac{Q}{Q_3}\right)^2 M \text{ \&c.}\ldots[71]$$

where $Q_1+Q_2+Q_3$, &c $=Q$, the entire quantity of air in circulation per minute.

In [67], [68], [69], [70], and [71], it must be borne in mind that the pressures M, M_1, M_2, M_3, &c., are only found to bear the relationships to Q, Q_1, Q_2, Q_3, &c., there indicated, when each passage is free from the effects of natural ventilation, which may arise from the air in the passages having different temperatures, and consequently different densities, in the ascending and descending parts of such passages, giving rise to forces which are not proportional to the squares of the quantities of air in circulation in the same passage, and which may prevail to different extents in the connected passages of the same mine; these formulæ only being strictly applicable where such forces do not obtain; yet where they only exist to a small extent in proportion to the forces due to frictional resistances, contractions, &c., represented by M, M_1, M_2, M_3, &c., the formulæ may give useful approximations to the truth.

(48.) When several currents of air traverse, in common with each other, a passage unaffected by natural ventilation, if the quantities of air in the different currents are represented by Q_1, Q_2, Q_3, &c., and a series of corresponding resistances by M_1, M_2, M_3, &c., while the united current is represented by $Q=Q_1+Q_2+Q_3$, &c., and the actual pressure required to force one cubic foot of air per minute through the passage is denoted by M, we should evidently have

$$M_1 = \left(\frac{Q}{Q_1}\right)^2 M;\ M_2 = \left(\frac{Q}{Q_2}\right)^2 M;\ M_3 = \left(\frac{Q}{Q_3}\right)^2 M \text{ \&c.}\ldots[72]$$

provided we assumed the corresponding resistances of such values that

$$Q_1^2 M, = Q_2^2 M_2 = Q_3^2 M_3 = Q^2 M;$$

in which case we could calculate the expenditure of pressure, from any of the separate currents, or from the united current, encountered in the passage in question—the resistances M_1, M_2, M_3, &c., being, however, hypothetical—a process which may, in some instances, be useful in reducing the calculations, whether in investigating the theory of ventilation, or in determining the resistances which any particular current of air actually

encounters, as distinguished from others with which it may in some parts of its route be intermixed.

(49.) In order to exhibit in a general point of view the benefits arising from "splitting" or dividing the air in mines, into different currents, each having a portion of the workings of the mine allotted to it for ventilation, it will be assumed that the effects of natural ventilation do not affect the results, which will be true of mines having all the workings situated in the same horizontal plane, or, under the contrary circumstances, of the workings lying at an inclination to the horizon, provided the air preserves the same temperature throughout the whole, and there is but one downcast and one upcast shaft, as this will render the investigation more simple.

As, however, in this part of the subject reference will be made to the coefficient of friction, it may not be amiss here to present a table shewing the actual value of this coefficient, under different circumstances, as determined from experiments made by MM. Girard, Daubuisson, and Péclet.

TABLE 1.

Shewing the value of the coefficient of friction K, as used in the preceding formulæ; being the height in feet of air column, required to overcome the frictional resistance encountered by one cubic foot of air per minute, passing through a passage presenting one foot area of section and one foot area of rubbing surface to the air.

Nature of the material composing the Air-way.	State of the internal surface of the material composing the Air-way.	GENERAL TEMPERATURE OF THE AIR.		
		COOL.		HOT.
		OBSERVERS' NAMES.		
		Girard.	Daubuisson.	Péclet.
Cast Iron....	Tarred or pitched inside — after long use....	$\frac{1\cdot005}{100,000,000}$	.....	.....
	Covered with soot after long use as a chimney.	.....	.....	$\frac{5\cdot2917}{100,000,000}$
Sheet Iron ..	Rusty	$\frac{2\cdot7517}{100,000,000}$	.....	.....
	New, and free from rust and soot.	.....	.....	$\frac{10\cdot583}{100,000,000}$
Burnt Earth or Pottery.	New, clean and free from soot....	.....	.....	$\frac{26\cdot881}{100,000,000}$
Tinned Iron....	Tin upon Iron....	.....	$\frac{2\cdot54}{100,000,000}$	.....

(50.) The general features of the mode about to be pursued to exhibit the effects of dividing the air by splitting it into different currents is suggested by the perusal of Mr. Combes' remarks on the same subject.

Suppose a mine, having one downcast and one upcast shaft, and an extent of workings free from the interference of natural ventilation in any part of them, composed entirely of galleries having the same area and perimeter of section in all their extent, and that such workings present a rubbing surface to the air, which in all parts has precisely the same coefficient of resistance; suppose, further, that all the workings, excepting a short distance very near the bottoms of the shafts, may be successively divided into any number of different groups, for ventilation by distinct currents of air, and so that each group, whatever may be their number, shall possess exactly the same development of galleries, and the same number of angles or turnings, and be each similarly situated with respect to the points where the air divides itself and again re-unites before ascending the upcast shaft; and let the following notation be adopted—

M=The pressure per unit of surface, or head of air-column, required to overcome the frictional resistances in the shafts, and the galleries extending from the points of division and re-union of the air to the shafts, and which are consequently traversed, in the same manner as the shafts themselves, by the whole of the air.

A=The area of the upcast shaft, in feet.

Q=The cubic feet of air per minute, ventilating the whole of the mine.

P=The ventilating pressure employed, expressed in height in feet of air-column, being in fact the same as $D_0 - U_0$ in our preceding investigations.

L=The length in feet, of the whole extent of the air-ways lying between the points where the air divides and again re-unites, respectively; but not including the shafts, and portions of air-way extending from them to the points of division and re-union.

c=The perimeter of the section of the air-ways which form the different groups of workings, expressed in feet.

a=The area of the uniform section of the air-ways, admitting of division into groups, expressed in superficial feet.

k=The coefficient of friction, suited to the nature of the air-ways which are divisable into groups, as described.

n=The variable number of groups into which the workings are divided for the purpose of separate ventilation.

Then by [10], ($\frac{Q^2}{A^2}$ being taken instead of the square of the velo-

city, to which it is equal,) we have $\frac{Q^2}{231600\,A^2}$ for the pressure in head of air-column, due to the velocity with which the air leaves the top of the upcast shaft; and $P - \frac{Q^2}{231600\,A^2}$ will be the pressure remaining applicable to the resistances; the resistances in the shafts and the undivided parts of the air-ways will require a pressure$=Q^2\,M$ to overcome them, leaving $P - \frac{Q^2}{231600\,A^2} - Q^2\,M$ to overcome the resistances which present themselves in the portion of the workings admitting of being divided into groups, as already explained; the resistance in these workings before splitting the air at all, according to [63], would be expressed by $Q^2\,\frac{k\,L\,c}{a^3}$; but if they were divided into n perfectly equal and similar groups, the effect would be equivalent to increasing the area open to the air, n times, or to (n a); while the rubbing surface exposed by the air-ways, L c, would remain unaltered, and, therefore, the pressure due to the resistances in question would become $Q^2\,\frac{k\,L\,c}{(n\,a)^3}$; or if we consider it in another point of view, and look upon the area as becoming (n a), and the length of passage pursued by the air, as being reduced to $\frac{L}{n}$ we must also consider that the perimeter of the section of the air-way allotted to each group is unaltered, and the sum of all the perimeters in the different groups is therefore n c; and if for L we substitute $\frac{L}{n}$, we must at the same time substitute n c for c, and this gives the same result, or $Q^2\,\frac{k\,L\,c}{(n\,a)^3}$, as the pressure due to the resistances alluded to, when the air is divided into n different splits or divisions; the resistance just alluded to being added to those before mentioned, will indicate the total expenditure of ventilating pressure, which must be equal to the entire pressure P, employed, or

$$P = \frac{Q^2}{231{,}600\,A^2} + Q^2\,M + Q^2\,\frac{k\,L\,c}{(n\,a)^3} \quad \ldots\ldots\ldots\ldots [73]$$

and hence

$$Q = \sqrt{\frac{P}{\frac{1}{231{,}600\,A^2} + M + \frac{k\,L\,c}{n^3\,a^3}}} \quad \ldots\ldots\ldots\ldots [74]$$

when the air is divided into n splits of equal amount: before the air is split at all, and when the whole column is required to traverse successively all the workings, n becomes equal to unity, and consequently

$$Q = \sqrt{\frac{P}{\frac{1}{231{,}600\ A^2} + M + \frac{k\,L\,c}{a^3}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [75]$$

Let it now be presumed that, in the example mine we have endeavoured to describe, the ventilation is caused by a pressure equal to that arising from a column of air 200 feet high, the area of the upcast shaft being taken at 100 superficial feet; the value of M, or the head of air-column due to the shaft and other unreducible resistances, when one cubic foot of air per minute is in circulation, we will suppose to be ·000,000,014,568,4 feet; the extreme minuteness of this number arises from the quantity of air forming the unit of circulation, being only one cubic foot per minute; the coefficient of resistance in the divisable parts of the workings we will suppose to be $k = \frac{3{\cdot}03030}{100{,}000{,}000}$; the entire length of such passages 50 miles or 264,000 feet; the perimeter of the section of these air-ways we will take at 30 feet = c; and its area a = 40 feet; then before splitting the air we should have for the quantity of air in circulation, by [75]

$$Q = \sqrt{\frac{200}{\frac{1}{231{,}600 \times 100^2} + {\cdot}000{,}000{,}014{,}568{,}4 + \frac{{\cdot}000{,}000{,}030{,}303 \times 264{,}000 \times 30}{40^3}}} = 7{,}288$$

cubic feet per minute.

If we conceive the air in the same mine to be divided, by splitting, into 10 equal currents, each traversing only one-tenth of the divisable part of the workings, we should then have, by [74]

$$Q = \sqrt{\frac{200}{\frac{1}{231{,}600 \times 100^2} + {\cdot}000{,}000{,}014{,}568{,}4 + \frac{{\cdot}000{,}000{,}030{,}303 \times 264{,}000 \times 30}{10^3 \times 40^3}}}$$

=103,280 cubic feet per minute, instead of the former quantity 7,288 cubic feet per minnte, each of the 10 splits being 10,328 cubic feet; so that upwards of 14 times the quantity of air would be introduced into the mine by the same amount of ventilating pressure per unit of surface, by being divided into 10 equal splits, as compared with its not being divided or split; each of the splits actually embracing more air than the entire quantity, before splitting was resorted to. It must, however, be noticed, that to maintain the same ventilating pressure for different quantities of air, requires that the *power*, whether obtained by furnace action

or by machinery, driven by engine power, should increase in the same proportion as the quantity of air in circulation is increased, and the consumption of fuel will, in either case, follow the same proportion. To have obtained an equal increase, without resorting to splitting the air, would have required the power and consumption of fuel to have increased in the ratio of the *cube* of the quantity of air.

In the case we have taken, the resistances arising in the shafts and undivided parts of the air-ways near them, amounts to one-third of the entire pressure employed when the air is divided into 10 equal parts, and this is no unusual proportion to be met with in practice, had it been of less amount the benefits of splitting the air would have been greater. By substituting successively 1, 2, 3, 4, &c., for n, in [74], as the number of equal currents into which the air-ways are divided, we obtain data for constructing the following table—

TABLE 2.

Table, shewing the result of dividing such a mine as that supposed for example into different numbers of similar and equal parts, to be ventilated by separate currents, under a constant ventilating pressure.

A No. of equal currents or splits of air.	*B* Total quantity of air circulating per minute, in cubic feet.	*C* Increase in the gross quantity due to each split added.	*D* Quantity of air in each split or current.	*E* Increase in the quantity of air in each split.	*F* Decrease in the quantity of air in each split.
1	7,288	.....	7,288	....	....
2	20,328	13,040	10,164	2,876	....
3	36,038	15,710	12,013	1,849	....
4	52,129	16,091	13,032	1,019	....
5	66,667	14,538	13,333	301	....
6	78,568	11,901	13,095	....	238
7	87,706	9,138	12,529	....	566
8	94,652	6,946	11,831	....	698
9	99,652	5,000	11,072	....	759
10	103,280	3,628	10,328	....	744
11	105,940	2,660	9,631	....	697
12	107,927	1,987	8,994	....	637
13	109,402	1,475	8,416	....	578
14	110,533	1,131	7,895	....	521
15	111,421	888	7,428	....	467
16	112,102	681	7,006	....	422
17	112,641	539	6,626	....	380
18	113,062	421	6,281	....	345
19	113,422	360	5,970	....	311
20	113,704	282	5,685	....	285
29	114,883	.....	3,962	....	....
30	114,939	56	3,831	....	131
39	115,227	.....	2,955	....	....
40	115,245	18	2,881	....	74
49	115,347	.....	2,354	....	....
50	115,355	8	2,307	....	47
99	115,455	.....	1,166	....	....
100	115,456	1	1,155	....	11
Infinity.	116,003	When the air does not traverse the workings.			

(51.) If, however, in the same mine which has been taken in the foregoing example, we were to presume, that, instead of the pressure employed per unit of surface being constant, the *horses' power* exerted to produce ventilation remained constant, as would be the case where fans, Harty pumps, and other machines, are employed in the production of ventilation; then the effects of dividing such mine into different numbers of equal groups, for separate ventilation, would be somewhat different as regards the resulting quantities of air, as will appear if we let, (as in formula [46,])

H=Horses' power of engine; and further substitute in [46], the value of $p+p'$, which will evidently be w P, where w is the weight in lbs. per cubic foot of air of the density of that in which P is estimated, (for finding the value of w see [43],) we obtain

$$H = \frac{Q\,w\,P}{33{,}000} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots [76]$$

and

$$P = \frac{33{,}000\,H}{w\,Q} \quad \ldots\ldots\ldots\ldots\ldots\ldots [77]$$

If we further presume that the head of air-column P, is estimated of the density due to dry air of the temperature of 61°, under a pressure of 30 inches of mercury, we find, by [43], that

$$w = \frac{1{\cdot}3244 \times 30}{459+61} = {\cdot}076407 \text{ lbs.}$$

which being substituted in [77], gives

$$P = \frac{33{,}000\,H}{{\cdot}076407\,Q}$$

and if this value of P be substituted in [74], we obtain the equation

$$Q = \sqrt[3]{\frac{\dfrac{33{,}000\,H}{{\cdot}076407}}{\dfrac{1}{231{,}600\,A^2} + M + \dfrac{k\,L\,c}{n^3\,a^3}}} \quad \ldots\ldots\ldots\ldots [78]$$

If we now presume the engine employed to produce the ventilation to be of 37·046 horses' power; and if we replace the literal quantities in [78], by their presumed numerical values in the mine which has been already adopted as an example, (excepting only the literal quantity n, denoting the number of equal splits of air,) we obtain a formula in which we have only to replace n by the number of splits into which we may conceive the air to be successively divided, to obtain the corresponding values of Q, or the quantity of air in cubic feet per minute put into circulation; the formula being,

$$Q = \sqrt[3]{\frac{\dfrac{33000 \times 37{\cdot}046}{{\cdot}076407}}{\dfrac{1}{231600 \times 100^2} + {\cdot}000{,}000{,}014{,}568{,}4 + \dfrac{{\cdot}000{,}000{,}030{,}303 \times 264{,}000 \times 30}{n^3 \times 40^3}}}$$

If the number of splits be increased without limit, and consequently the last expression in the denominator were rendered of no value; in other words, if the air only had to traverse the shafts, and the air-ways extending from them to the points where the currents divide and re-unite, respectively; then 37·046 horse power would put into circulation

$$Q = \sqrt[3]{\frac{\dfrac{33000 \times 37{\cdot}046}{{\cdot}076407}}{\dfrac{1}{231600 \times 100^2} + {\cdot}000{,}000{,}014{,}568{,}4}} = 102{,}175$$

cubic feet of air per minute.

Table 3 shews the results of dividing the same mine into different numbers of equal parts, for separate ventilation, when the power employed is constant.

TABLE 3.

Table, shewing the result of dividing such a mine into different numbers of similar and equal parts, to be ventilated by separate currents of air; the *power* being constant.

No. of equal currents or splits of air. *A*	Total quantity of air circulating per minute, in cubic feet. *B*	Increase of air due to each split added. *C*	Quantity of air in each split, in cubic feet, per minute. *D*	Decrease in the quantity of air in each split. *E*
1	16,198	.....	16,198	....
2	32,094	15,896	16,047	151
3	47,011	14,917	15,670	377
4	60,129	13,118	15,032	638
5	70,844	10,715	14,169	863
6	79,042	8,198	13,174	995
7	85,058	6,016	12,151	1,023
8	89,492	4,434	11,187	964
9	92,616	3,124	10,291	896
10	94,850	2,234	9,485	806
11	96,473	1,623	8,770	715
12	97,675	1,202	8,140	630
13	98,563	888	7,582	558
14	99,241	678	7,089	493
15	99,772	531	6,651	438
16	100,177	405	6,261	390
17	100,498	321	5,912	349
18	100,755	257	5,597	315
19	100,963	208	5,314	283
20	101,132	169	5,057	257
29	101,828	.....	3,511	....
30	101,861	33	3,395	116
39	102,037	.....	2,616	....
40	102,042	5	2,551	65
49	102,102	.....	2,084	....
50	102,106	4	2,042	42
99	102,166	.....	1,032	....
100	102,167	1	1,022	10
Infinity.	102,175	When the air does not traverse the workings.		

An examination of these tables will shew how very great is the increase in the air circulating, which may arise from judiciously splitting the air in a mine, whether the ventilating pressure be supposed to remain constant, as in Table 3, or, on the other hand, the power employed be supposed to be uniform; and the difference between the one and the other of these suppositions may be estimated by comparing the tables, one with the other, commencing the comparison at the point where the air is in each case supposed to be divided into 6 splits, the quantities then being nearly equal to each other.

In the example mine, if the resistances represented by M, as due to the shafts and air-ways near them, supposed to be traversed in every instance by the entire undivided current, had been of less amount, owing to the shafts being larger and the said air-ways of less extent, then the good effects of splitting the air would have been enhanced, as this invariable resistance would have been of less amount, so that a larger proportion of the total resistances would have been reduced by splitting the air.

If, for instance, the head of air-column due to these resistances had only been ·000,000,000,818,2 feet for the circulation of one cubic feet of air per minute, instead of ·000,000,014,568,4 feet, as has been presumed; then, for a constant pressure of the same amount as in Table 2, we should have the quantities represented by [74],

$$Q = \sqrt{\frac{200}{\frac{1}{231600 \times 100^2} + \cdot 000,000,000,818,2 + \frac{\cdot 000,000,030,303 \times 264,000 \times 30}{n^2 \times 40^2}}}$$

giving rise to the following table of results.

TABLE 4.

Table, shewing the result of dividing such a mine as that just described, into different numbers of similar and equal parts, to be ventilated by separate currents, under a constant pressure.

No. of equal currents or splits of air. *A*	Total quantity of air circulating per minute, in cubic feet. *B*	Increase in the quantity by each split added, in cubic feet, per minute. *C*	Quantity of air in each split or current, in cubic feet per minute. *D*	Increase of the quantity of air in each split, in cubic feet per minute. *E*	Decrease of the quantity of air in each split, in cubic feet per minute. *F*
1	7,302	.....	7,302	....	....
2	20,623	13,321	10,311	3,009	....
3	37,763	17,140	12,588	2,277	....
4	57,807	20,044	14,452	1,864	....
5	80,000	22,193	16,000	1,548	...
6	103,550	23,550	17,258	1,258	....
7	127,770	24,220	18,253	1,005	....
8	152,770	25,000	19,096	843	....
9	176,910	24,140	19,657	561	....
10	200,000	23,090	20,000	343	....
11	221,670	21,670	20,152	152	....
12	241,820	20,150	20,152	....	....
13	259,940	18,120	19,995	....	157
14	276,290	16,350	19,735	....	260
15	291,110	14,820	19,407	....	328
16	303,940	12,830	18,996	....	411
17	315,210	11,270	18,542	....	454
18	325,040	9,830	18,058	....	484
19	333,639	8,599	17,560	....	498
20	341,126	7,487	17,056	....	504
29	377,466	.....	13,016	....	....
30	379,472	2,006	12,649	....	367
39	390,256	.....	10,007	....	....
40	390,941	685	9,774	....	233
49	394,992	.....	8,061	....	....
50	395,285	293	7,906	....	155
99	399,383	.....	4,034	....	....
100	399,401	18	3,994	....	40
Infinity.	400,000	The quantity of air Q—which would be put into circulation if the air only traversed the shafts and air-ways extending from them to the points of the division or splitting, and reunion, respectively.			

It will be seen, that owing to the reduction in the amount of the constant resistances, the maximum quantity of air in Table 4 is 400,000 cubic feet per minute, under a ventilating pressure, of 200 feet of air, compared with a maximum quantity of only 116,003 cubic feet per minute, arising from the same ventilating pressure, in Table 2, although the general workings of the mine, in the two cases, present exactly the

same amount of resistance; the greater quantity being entirely due to the lesser shaft and constant resistances; and a comparison of the two tables will shew how much the quantities are affected by the supposed alteration in these resistances, when the workings are presumed to be divided into various numbers of equal parts, for separate ventilation; from whence the necessity of making the shafts and general air-courses in their immediate vicinity, of great sectional area, will appear, in order to produce a good and economical ventilation.

Adopting the same reduction in the amount of the shaft and constant resistances, and presuming that a constant *power* had been used to produce ventilation, of the same amount as in Table 3; viz., 37·046 horses' power, the quantities of air put into circulation under different numbers of equal splits, all other conditions being the same as in Table 3, would be given by the formula [78], or by

$$Q = \sqrt[3]{\frac{\dfrac{33000 \times 37{\cdot}046}{{\cdot}076407}}{\dfrac{1}{231600 \times 100^2} + {\cdot}000,000,000,818,2 + \dfrac{{\cdot}000,000,030,303 \times 264000 \times 30}{n^3 \times 40^3}}}$$

the results of which are shewn in Table 5.

TABLE 5.

Table, shewing the result of dividing such a mine as that described, into different numbers of similar and equal parts, to be ventilated by separate currents, under a constant power.

No. of equal currents or splits of air. *A*	Total quantity of air circulating per minute, in cubic feet. *B*	Increase in the quantity by each split added. *C*	Quantity of air in each split or current. *D*	Decrease of the quantity of air in each split. *E*
1	16,217	.....	16,217	....
2	32,404	16,187	16,202	15
3	48,500	16,096	16,167	35
4	64,420	15,920	16,105	62
5	80,000	15,580	16,000	105
6	95,088	15,088	15,848	152
7	109,510	14,490	15,644	204
8	123,153	13,643	15,394	250
9	135,790	12,637	15,082	308
10	147,360	11,570	14,736	346
11	157,840	10,480	14,349	387
12	167,250	9,410	13,937	412
13	175,500	8,250	13,500	437
14	182,790	7,290	13,056	444
15	189,260	6,470	12,617	439
16	194,785	5,525	12,174	443
17	199,570	4,785	11,739	435
18	203,700	4,130	11,317	422
19	207,275	3,575	10,909	408
20	210,365	3,090	10,518	391
29	225,150	.....	7,764	....
30	225,850	700	7,528	236
39	230,110	.....	5,900	....
40	230,377	267	5,759	141
49	231,965	.....	4,734	....
50	232,080	115	4,641	93
99	233,681	.....	2,360	....
100	233,688	7	2,337	23
Infinity.	233,921	When the air does not pass beyond the splitting point.		

With reference to Tables 2 and 4, where the ventilating pressure employed is supposed to remain constant, the consumption of fuel would be nearly proportional to the quantities of air exhibited in the tables as circulating, in the columns marked *B*; because if furnace ventilation were employed, the increase of temperature required to be imparted to the air to maintain a constant ventilating pressure would be the same; but the unities of heat, and consequently the consumption of fuel required to effect this,

would be nearly proportional to the quantity of air to be heated; the only reason for a deviation from this, being alterations in the loss by cooling in the shaft, &c.; and if, on the other hand, engine power were employed, the pressure being constant, the power itself would require to increase with the velocity of the air, and the consumption of fuel would increase in the same proportion.

In Tables 3 and 5 the consumption of fuel may be regarded as being constant, because, since the power is constant, the ventilating pressure multiplied by the velocity of the air must be constant; any increase in the quantity of air requiring to be heated by a furnace would, therefore, be accompanied by a proportionate decrease in the pressure, and consequently in the heat or temperature required to be imparted to it. If engine power were employed, then since the power is constant, the consumption of fuel may be regarded as being so likewise.

The resistances in the shafts and air-ways traversed by the undivided current, are, in Tables 2 and 3, taken at amounts not widely differing from cases met with in mines, so that these tables may be regarded as giving a more ordinary general view of the benefits arising from splitting the air into equal parts, than Tables 4 and 5, where these constant resistances have been presumed to be of unusually small amount, for the mere purpose of shewing the desirableness of reducing them to the lowest practicable amount.

In Tables 2 and 3, the constant resistances represented by $\frac{1}{231{,}600\ A^2} + M$, are probably fair representatives of these resistances as they frequently occur in practice; being, in fact, equal to one-half of the resistances which arise from those workings which we have supposed to be capable of division, for the purpose of separate ventilation; and, consequently, equal to one-third of the total resistances, when we suppose the air to be divided into 5 equal splits.

This conclusion is supported by the case of Hetton Colliery, as alluded to by Mr. Wood in his Paper on the Relative Value of the Furnace and the Steam Jet; where we find that when the shaft temperatures were very high, which would probably cause these resistances to assume an undue proportion to the total resistances, they formed, in one instance, 75 parts out of 115 of the resistances of the air-ways, and 96 parts out of 128 in another case: that is to say, in the former case $\frac{75}{190}$ of the total ventilating pressure; and $\frac{96}{225}$ of that pressure, in the latter case; where

a high upcast temperature would probably tend to make these proportions unusually great; while this would be further promoted by the general resistance of the mine itself being exceedingly small, as may be seen in (28). The following Table shews the cases in question.

TABLE 6.

Table, shewing the pressures expended in producing ventilation, in two experiments at Hetton Colliery; and the same, as allowed for in Tables 2 and 3, in this memoir.

	Average Temperature of Shafts.		Quantities of air per minute, in cubic feet.	Pressures, expressed in feet of air column, of the Temperature of the Down-cast Shafts.					Velocity of the air in the Up-cast Shafts, in feet per minute.
	Down-cast.	Up-cast.		Generating the Velocity at the top of the Up-cast Shaft.	Overcoming the resistances of the Shafts and Air-ways near them.	Sum of *D* & *E*.	Overcomes the resistances in the divided Air-ways.	Total Ventilating Pressure, being the sum of *F* & *G*.	
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*
Hetton, 1st case.	43°·5	178°	211,193	10·43	64·61	75·04	115·27	190·31	29·16
Hetton, 2nd case	43°·5	211°	225,176	12·37	84·18	96·55	128·45	225·00	32·57
Table 2, 5 Splits.	....	....	66,667	1·92	64·75	66·67	133·33	200·00	11·11
Table 3, 5 Splits.	....	....	70,844	2·17	73·12	75·28	150·57	225·85	11·81

In the first of the above experiments or cases at Hetton Colliery, the sum of the pressures due to the final or upcast shaft velocity, and to the resistances of the shafts and principal air-ways extending from them to the point where the gauge was fixed, was ·651 of the total ventilating pressure, and, in the second case, it was ·752 of the total ventilating pressure; being probably a larger proportion of the pressure producing ventilation in the latter than in the former case, owing to the greater amount of expansion in the air in the upcast shaft in the latter than in the former case, arising from the higher temperature prevailing in the furnace drift and in the upcast shaft; as the resistances of a frictional character probably increase with the square of the velocity, quite independent of any change in the density of the air, so long as it exists under the same barometrical pressure.

(52.) In what has been stated relative to the effects of splitting the air in a mine, all the splits have been presumed to be of equal amount, both as to quantity of air, and to the extent of workings ventilated by

them, which conditions are most favourable to the increase of ventilation, but are seldom or never fully attainable in mines.

In order to show the effects of splitting the air in mines, into currents of different amounts, ventilating workings differing in extent and resistances, let us take the same mine which we have made use of in constructing Tables 2 and 3, where the constant resistances are taken at an amount not unlikely to be met with in practice; and let it be presumed that into whatever number of divisions the 50 miles of galleries are conceived to be divided for separate ventilation, each of the currents, splits or branches from, and also reunites to, the general or main current at the same points. This supposition, in the mine we have supposed, involves the necessity of the pressure required in each of the separate currents, being equal to each other, as the air will naturally divide itself in such a manner as to suit this condition. In general, it may be presumed, that the quantity of air in each split should be proportional to the length of the galleries allotted to it for ventilation, and we will therefore adopt this proportion in the present illustration, involving the necessity of the resistances offered by the whole of the routes, excepting the longest one, being so artificially increased, by regulators or contractors placed in them, as to make the expenditure of pressure in each of the shorter routes as great as that in the longest one, even although the air in them is less in amount, as their length is shorter than the longest route; and, under these circnmstances, it is evident that the ventilation will be less effectual, on the whole, than if the splits had been equal and no artificial resistances had been created, seeing that into whatever number of splits the air is divided, all will be throttled excepting the largest one.

Adhering to the notation already adopted in discussing the effects of splitting the air in a mine, and in addition letting

l_1, l_2, l_3, &c., represent the lengths of the separate divisions for distinct ventilation, the longest one being represented by L, and letting

q_1, q_2, q_3, &c., represent the quantities of air circulating in these divisions, respectively; that in the longest and uncontracted division being denoted by Q, then we have

$$\mathrm{L} = L + l_1 + l_2 + l_3, \text{ \&c.} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [79]$$

and also

$$\mathrm{Q} = Q + q_1 + q_2 + q_3, \text{ \&c.} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [80]$$

and we have already taken in the supposed mine

$M = \cdot 000,000,014,568,4$

$A = 100$

$k = \cdot 000,000,030,303$

$L = 264,000$

$c = 30$

$a = 40$

and $P = 200$

giving, as the quantity of air before splitting, or when $n=1$,

$$Q = \sqrt[3]{\frac{200}{\frac{1}{231,600 \times 100^2} + \cdot 000,000,014,568,4 + \frac{\cdot 000,000,030,303 \times 264,000 \times 30}{1 \times 40^3}}}$$

$= 7,302$ cubic feet per minute, as before found.

Before splitting the air the pressure due to the frictional resistances of the mine, lying beyond the points where the air is divided and again reunited, respectively, is expressed by

$$P - Q^2\left(\frac{1}{231,600\,A^2} + M\right) \quad \ldots\ldots\ldots\ldots\ldots [81]$$

where M is the specific resistance of the downcast and upcast shafts, furnace, furnace drift, and united air-ways, where the air is not split.

If we now conceive the passages of the mine lying beyond the points of division and reunion of the currents of air, to be divided into distinct parts for separate ventilating currents, as before stated, and that artificial obstructions or regulators are introduced into each of the routes, excepting the longest one, so as to reduce the quantities of air circulating in such routes, until the quantity in each becomes proportional to the length of its own route which it is destined to ventilate; and if by M we denote the specific resistance of the longest route, by L its length, and by Q the quantity of air circulating in it, in accordance with the notation indicated,

$$P - \left(\frac{1}{231,600\,A^2} + M\right)Q^2 = Q^2 M \quad \ldots\ldots\ldots\ldots\ldots [82]$$

but since we have presumed the quantities Q, q_1, q_2, q_3, &c., to be proportional to L, l_1, l_2, l_3, &c., respectively, the lengths they have to ventilate, we get

$$Q : L :: Q : L :: q_1 : l_1 :: q_2 : l_2 :: q_3 : l_3, \text{ \&c.} \quad \ldots\ldots [83]$$

and hence

$$Q = Q\frac{L}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [84]$$

and by substituting this value of Q in [82], we get

$$P - \left(\frac{1}{231{,}600\,A^2} + M\right)Q^2 = Q^2 \frac{L^2}{L^2} M \text{ .....[85]}$$

and hence

$$P = Q^2 \left\{ \frac{1}{231{,}600\,A^2} + M + \frac{L^2}{L^2} M \right\} \text{ .....[86]}$$

and

$$Q = \sqrt{\frac{P}{\frac{1}{231{,}600\,A^2} + M + \frac{L^2}{L^2} M}} \text{ .....[87]}$$

After finding the value of Q by [87], it will be easy to find the values of the separate currents Q, q_1, q_2, q_3, &c., because by [84],

$$Q = \frac{L}{L} Q;\ q_1 = \frac{l_1}{L} Q;\ q_2 = \frac{l_2}{L} Q;\ q_3 = \frac{l_3}{L} Q \text{ \&c.....[88]}$$

In the case in hand, the specific resistance M will be $\frac{k\,L\,c}{a^3}$, and hence

$$\frac{L^2}{L^2} M = \frac{k\,L^3\,c}{L^2\,a^3} \text{ .....[89]}$$

as the air-ways are supposed to have an uniform area and perimeter of section throughout; so that in this instance,

$$Q = \sqrt{\frac{P}{\frac{1}{231{,}600\,A^2} + M + \frac{k\,L^3\,c}{L^2\,a^3}}} \text{ .....[90]}$$

Applying this formula to the mine which has been supposed for example, as in Tables 2 and 3, where the shaft resistances are greatest; if, in the first place, we assume the pressure to remain constant, as in Table 2, at 200 feet in height of air column; and suppose the air to be divided into two currents, one of the routes being half the length of the other, and one of the currents, in like manner, being equal to one-half of the other, to circulate in the routes to which they are respectively proportional, we get

$$Q = \sqrt{\frac{200}{\frac{1}{231{,}600 \times 100^2} + \cdot 000{,}000{,}014{,}568{,}4 + \frac{\cdot 000{,}000{,}030{,}303 \times (26400 \times \frac{1}{2})^3 \times 30}{264{,}000^2 \times 40^3}}}$$

$= 13{,}096$ cubic feet of air per minute; whilst by Table 2, we see that if the routes had been of equal length, and aired by equal currents, so as to have required no regulators, the quantity of air in the two currents would have been 20,328 cubic feet; so that we only obtain an increase of 5,808

on the original quantity before splitting, instead of an increase of 13,040, as is stated in Table 2, to result from the splits being equal to each other.

The quantity of air in the longest route would in this case be $\frac{2}{1+2} \times 13{,}096 = 8{,}731$ cubic feet; the quantity in the shorter route being $\frac{1}{1+2} \times 13{,}096 = 4{,}365$ cubic feet per minute. See [88].

It may be seen that instead of using the absolute lengths of the routes, in these calculations, quantities proportional to them are used, but as they only occur in their ratios, this will not affect the correctness of the results.

If we next conceive the mine to be divided into 3 parts, the lengths of which, and the currents of air traversing them are respectively proportional to the numbers 1, 2, and 3; then

$$Q = \sqrt{\frac{200}{(\cdot 000{,}000{,}000{,}431{,}6 + \cdot 000{,}000{,}014{,}568{,}4) + \frac{\cdot 000{,}000{,}030{,}303 \times (264{,}000 \times ,)^2 \times 30}{264{,}000^2 \times 40^3}}}$$

$= 20{,}333$ cubic feet of air per minute, whilst by Table 2 it appears that if the three routes had been of equal length, and aired by equal currents, so as to have required no regulators, the quantity would have been 36,038 cubic feet, instead of only 20,333 cubic feet; even under the same ventilating pressure.

The quantities of air in each of the routes would be,

In the longest route..... $\frac{3 \times 20{,}333}{1+2+3} = 10{,}166$ cubic feet.

In the next shorter route.. $\frac{2 \times 20{,}333}{1+2+3} = 6{,}778$ " "

In the shortest route .... $\frac{1 \times 20{,}333}{1+2+3} = 3{,}389$ " "

being quantities respectively proportional to the lengths of their routes.

In a similar manner to the above, by the use of formula [90] to determine the gross quantity Q, and that of [88] to determine the values of Q, q_1, q_2, q_3, &c., the following table has been constructed to show the quantities of air due to the constant pressure, as the same mine is supposed to be successively divided into 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 distinct parts for separate ventilation, always, however, forming in their lengths an arithmetical series, having for a common difference the length of the shortest route, and aired or ventilated by quantities of air directly proportional to their respective lengths; in the column C, of the table, are exhibited the quantities of air which would have been put into circulation in each split in the same mine, presuming the same constant pressure had been employed, and that the mine, instead of being divided and

ventilated in the manner stated, had been divided into equal numbers of splits, of equal lengths, and ventilated by currents of equal amount, as in Table 2; a comparison of the quantities in columns *B* and *C* will show the great advantages of having the resistances due to a given quantity of air, and the currents themselves, as nearly of equal amount as possible when the general requirements of all parts of the mine are nearly equal.

TABLE 7.

Number of splits of air.	Quantities when the splits are an arithmetical series.	Quantities when the splits are the same in number, but all equal.	Differences, lost by the inequality of the currents.	Loss per cent. of greater quantity
A	*B*	*C*	*D*	*E*
1	7,288	7,288		
2	13,326	20,328	7,002	34½
3	20,333	36,038	15,705	43½
4	28,006	52,120	24,123	46¼
5	36,051	66,667	30,616	46
6	44,180	78,568	34,388	43¾
7	52,131	87,706	35,575	40½
8	59,680	94,652	34,972	37
9	66,667	99,652	32,985	33
10	72,991	103,280	30,289	29¼

An examination of Table 7 clearly shows the great increase which can be made in the quantity of air ventilating a mine, having the resistances of the routes and the quantities of air ventilating them improperly proportioned; by so altering them, that the squares of the quantities of air in each route, taken from its entering, up to the time of its leaving the mine, multiplied into the specific resistances, shall be of equal amount in each, (presuming the mine to be free from natural ventilation, or, otherwise allowing for its effects,) while the quantities are proportioned to the requirements of the routes they ventilate, after the removal of all artificial contractors or regulators.

The table presumes the pressure to remain constant before and after

the alteration; by furnace action it is probable that this would be nearly realized, in many cases, without altering the furnace, as the fuel consumed may be presumed to be nearly proportional to the quantity of air passing over the same furnace.

(53.) If, however, a constant *power*, requiring a constant consumption of fuel, were employed before and after such a change in splitting the air, the benefits resulting would not be of so great an amount. And if before the change of air, the shorter routes had an undue share of the air, the increase in the total quantity in the mine, by such a change, would not be so great as in the table, although the actual benefits might be so, from an improved mode of distributing the air. If, on the contrary, the shorter routes had less than their requirements, in proportion to the whole, the change would be of still more benefit than is exhibited by the mere quantities; as, while they would be increased by such a change, in a higher ratio than is shown by the tables, the increased quantity would be more properly distributed.

By substituting in formula [90], the value of P in [77], and reducing, we obtain

$$Q = \sqrt[3]{\frac{\frac{33000\,H}{\cdot 076407}}{\frac{1}{231{,}600\,A^2} + M + \frac{k\,L^3\,c}{L^2\,a^3}}} \quad \ldots\ldots\ldots\ldots\ldots [91]$$

the value of w being taken at ·076407 as before.

If we apply this formula to the mine already taken for example, and presume the ventilating power employed to be the same as in Table 3, or 37·046 horse-power; and, in the first place, suppose the mine to be divided into two different parts, in the ratio of 1 to 2, for separate ventilation, we obtain,

$$Q = \sqrt[3]{\frac{\frac{33{,}000 \times 37\cdot 046}{\cdot 076407}}{\frac{1}{231{,}600 \times 100^2} + \cdot 000{,}000{,}014{,}568{,}4 + \frac{\cdot 000{,}000{,}030{,}303 \times (264000 \times \frac{2}{3})^3 \times 30}{264000^2 \times 40^3}}}$$

= 24,220 cubic feet of air per minute which would pass through the mine, $\frac{2}{1+2}$ of it in the route of which the length is 264000 × $\frac{2}{1+2}$ = 176,000 feet; and $\frac{1}{1+2}$ of it in the other route of which the length is 264,000 × $\frac{1}{1+2}$ = 88,000 lineal feet; that is, presuming the necessary regulator to be introduced into the shorter route.

The following table has been constructed from the formula [91].

TABLE 8.

Number of Currents.	Quantities of air in the entire mine, when the splits form the arithmetical ratio stated.	Quantities of air in the entire mine, when the splits are equal, as in Table 5.	Differences, lost by the inequality of the routes and splits.	Loss per cent. of greater quantities.
	Cubic feet ℔ minute.	Cubic feet ℔ minute.	Cubic feet ℔ minute.	
1	16,198	16,198		
2	24,220	32,094	7,874	24½
3	32,100	47,011	14,911	31¾
4	39,737	60,129	20,392	34
5	47,022	70,844	23,822	33½
6	53,850	79,042	25,192	32
7	60,130	85,058	24,928	29½
8	65,804	89,492	23,688	26½
9	70,844	92,616	21,772	23½
10	75,257	94,850	19,593	20¾

A comparison of Tables 7 and 8 shows that in the case of the power employed being constant, the loss arising from the inequality of the extent of workings and of the quantities of air ventilating them in the different splits, although of serious amount, is yet rather less than the loss arising from the same cause when the pressure per unit of surface is constant.

When the power is constant, the ventilating pressure will be inversely proportional to the quantity of air in circulation in a given time, and when the pressure is constant, the power will be directly proportional to the quantity of air circulating in a given time.

It is true, that by contracting the shorter routes to a less extent than has been presumed in constructing the tables, a larger quantity of air than is shown in the tables, would be found to circulate in the particular routes where such reduced contraction existed, but this would have the effect of increasing the amount of pressure absorbed by the general resistances in the shafts and undivided air-ways near them, and would, con-

sequently, leave less pressure to overcome the resistances in the air-ways over which the splits are effected, and would thus reduce the quantity of air in the whole of the other splits. Since, in general, we may regard the quantity of gas given off, and the number of workmen employed in various parts of a mine, to be rather proportional to the extent of galleries in each part or split, then in any other proportion, the principle which has been adopted for constructing the tables cannot but be regarded as a legitimate one for a general illustration; notwithstanding which, it will doubtless often be proper to depart from the broad principle just exhibited, as these conditions will seldom obtain to the full.

(54.) We may obtain a more full view of the effects of dividing the air into equal and unequal splits, the latter in the proportions already alluded to, by the following method.

We have [73] for the pressure due to ventilation, when the splits are of equal amount,

$$P = Q^2 \left\{ \frac{1}{231600\,A^2} + M + \frac{k\,L\,c}{n^3\,a^3} \right\} \ldots\ldots\ldots\ldots [92]$$

and by [77], we have

$$P = \frac{33000\,H}{\cdot 076407\,Q}$$

when $w = \cdot 076407$, as the weight of a cubic foot of the air in which the height of the ventilating column P is estimated; and by substituting this value of P in [92], we obtain the equation

$$\frac{33000\,H}{\cdot 076407\,Q} = Q^2 \left\{ \frac{1}{231600\,A^2} + M + \frac{k\,L\,c}{n^3\,a^3} \right\} \ldots\ldots\ldots [93]$$

and hence

$$H = \frac{\cdot 076407}{33000}\,Q^3 \left\{ \frac{1}{231600\,A^2} + M + \frac{k\,L\,c}{n^3\,a^3} \right\} \ldots\ldots [94]$$

by which we can calculate the number of horses' power which would be required to put any quantity of air, per minute, into circulation, in the example-mine alluded to in constructing Tables 2 and 3, so long as the whole of the splits are equal to each other both as to quantity of air and extent of gallieries.

From [91] we obtain

$$H = \frac{\cdot 076407}{33000}\,Q^3 \left\{ \frac{1}{231600\,A^2} + M + \frac{k\,L^3\,c}{L^2\,a^3} \right\} \ldots\ldots [95]$$

whereby we can determine the horses' power required to circulate, in the same example mine, the quantity of 66,667 cubic feet per minute when the mine is divided into splits, the routes of which are in an arithmetical

progression as to length, having the common difference equal to the shortest route, and all, excepting the longest, being so contracted as to render the air in each, proportional to the extent of the galleries ventilated by it.

From these formulæ, as a basis, the following table has been constructed :—

TABLE 9.

Table, shewing the ventilating pressures, expressed in feet of air column, weighing ·076407 lbs. per cubic foot; and the number of horses' power required to put the constant quantity of 66,667 cubic feet of air per minute into circulation, in the example mine, to which tables 2, 3, 6, 7, and 8, bear reference; both on the supposition of the divisions for separate ventilation being equal to each other, and ventilated by equal quantities of air; and also on the supposition of the length of galleries in the divisions forming an arithmetical series, with a common difference equal to that of the least division; ventilated by air in proportion to their respective lengths; effected by regulators: with the number of cubic feet of air circulated by each lb. of coal consumed by an engine, and by each horse-power per minute.

Number of splits or currents	When the currents are equal to each other.					When the currents are unequal, as above.				
	Pressure required in head of air column.	Horses' power required.	Fuel @ 12 lbs. per horse-power, per hour.	Cubic feet of air circulated.		Pressure required in head of air column.	Horses' power required.	Fuel @ 12 lbs. per horse-power, per hour.	Cubic feet of air circulated.	
				℔ horse-power, per minute.	Per lb of coal.				℔ horse-power, per minute.	Per lb. of coal.
A	*B*	*C*	*D*	*E*	*F*	*b*	*c*	*d*	*e*	*f*
1	16,733	2582·9	516·6	26	129	16,733	2582·9	516·6	26	129
2	2,151	332·0	66·4	201	1,004	5,005	772·5	154·5	86	431
3	684	105·6	21·0	631	3,156	2,151	332·0	66·4	201	1,004
4	327	50·5	10·0	1,320	6,602	1,133	174·9	35·0	381	1,906
5	200	30·9	6·2	2,160	10,794	684	105·6	21·0	631	3,156
6	144	22·2	4·4	3,000	14,997	455	70·3	14·1	948	4,742
7	116	17·8	3·6	3,738	18,688	327	50·5	10·0	1,320	6,602
8	99	15·3	3·1	4,353	21,765	250	38·5	7·7	1,731	8,653
9	89	13·8	2·8	4,825	24,125	200	30·9	6·2	2,160	10,794
10	83	12·8	2·6	5,183	25,914	167	25·8	5·2	2,589	12,943
11	79	12·2	2·4	5,453	27,266	144	22·2	4·4	3,000	14,997
12	76	11·8	2·4	5,660	28,298	127	19·7	3·9	3,391	16,956

An examination of Table 9 will show the great reduction in the pressure and power required for sending one and the same quantity of air through a mine, which is effected by splitting the air, and likewise the great economy which it effects in the consumption of fuel. These benefits, arising from splitting the air, it will be seen, are very much greater for equal numbers of splits, when they are equal to each other, than when they are unequal, and form an arithmetical progression of the character described. In fact, we see that for the same quantity of air sent through the same mine, the economy of pressure per unit of surface, power, and fuel, is just the same for two equal, as it is for three unequal

splits; for three equal, as for five unequal splits; and for four equal, as for seven unequal splits; and so on—it being the same for six equal, as for eleven splits in arithmetical progression, under the circumstances described in constructing the table; the same economy being, in general terms, only effected by unequal splits, when their number is only less than double the number of equal splits by unity, which are requisite to effect the same economy.

In general we may continually increase the quantity of air circulating in a mine by dividing it into an increasing number of splits, while the power employed remains constant; yet there is a point beyond which, if this division or splitting of air were carried, the slow rate at which the air in each individual split would travel might give rise to great inconvenience, and possibly to danger itself, as it would allow gases to lodge in spaces left in the roof by falls of stone, and in excavations a little in advance of the openings effected for the passage of the air; and any sudden generation of gas might not be diluted so quickly as if the current travelled faster; besides, when a shot was fired by a workman, giving off smoke, it might be an inconveniently long time in getting carried beyond his fellow-workmen to leeward of him.

CHAPTER VI.

General Considerations relating to the Application of the Theory of Ventilation towards guiding the Practice of it in Mines—the Indications of Pressure Gauges.

(55.) It would, perhaps, sometimes conduce to the better ventilation of mines, could we calculate, before making any change of air, the exact quantities which would circulate in each of the principal and minor splits or divisions under any given or assumed ventilating pressure, as it would enable us to compare the results of any number of proposed modes of dividing the air, which might be presented by the extent and position of the workings, and thus enable us to select and carry out that particular mode which would, under all the circumstances of the case, give the most desirable results The general laws recited in the first chapter of this memoir appear to contain the elements required for carrying this into effect, if it were possible to measure the dimensions of all the air-ways, and if we could determine the value of the coefficient of friction k, as due to each part of the same, by mere observation as to the nature and state of the internal surfaces presented to the moving air over their entire extent; to those at all acquainted with the ordinary condition of the air-ways in mines, and of their great extent and continually-varying contour of section, together with the frequent occurrence of inaccessible fallen air-ways, only used as auxiliary to others in an accessible state, and the leakage of air through goaves, doors, and stoppings, not only will this proceeding appear to be a laborious operation, but in many cases absolutely impossible.

If, however, we had a ready and easily-applied means of ascertaining the amount of resistance due to each air-way, and each part of an air-way, intended to be detached from or added to any other division after a proposed change of air, there would appear to be some chance of the

laws of ventilation being studied and made use of in the practical ventilation of mines; at least this is the hope indulged by the writer, in the belief that, in certain cases, the result would be an improved ventilation, with its accompanying effects on the health and comfort of the miners, and the longer duration of the perishable materials used in mines.

The use of extremely-sensitive barometrical instruments, or pressure gauges, suggests itself as being the most likely mode of determining the amount of resistance to the circulation of air, offered by an air-way, or part of an air-way, without incurring the great amount of trouble, or encountering directly, the difficulties which present themselves in attempting to do this in the more obvious manner above mentioned.

When an air-way, or part of an air-way under consideration, so returns upon itself that the two extreme ends of it are only separated by the intervention of a door or stopping, or at most by a distance of unventilated or dumb air-way on each side of such a door or stopping, the use of the ordinary water-gauge, which has often been employed in recent experiments, would appear, at least, to involve all the principles required for determining the amount of the resistances encountered by the air after passing one side of the stopping or dumb air-way, and up to the time of its reaching the other or return side of the stopping or dumb air-way in which the gauge is fixed; when, however, the air-way or portion of air-way of which we wish to determine the resistance, does not return upon itself in the manner alluded to; and for the purpose now in view this will perhaps often be the case; the water-gauge will no longer be applicable, as it cannot, under such circumstances, be applied to determine the difference of pressure under which the air exists at the two ends of the air-way, or portion of air-way under observation; and other means will require to be resorted to. Indeed, when we consider that the total amount of resistances encountered by the air, from its entering, up to the point where it leaves the mine, seldom exceeds two to three inches of water-gauge, representing a pressure of 10 to 15 lbs. per superficial foot, and that the parts of air-ways which may be put under separate notice for effecting changes of ventilation, may often not present resistances amounting to more than ten, twenty, or thirty per cent. of the total resistance offered by the mine, the displacement shown by a water-gauge, on a scale so short, would scarcely be observable; particularly when it is considered that many of the kinds of resistances indicated, decrease in amount, not simply as the quantity, but in the higher ratio of the square of the quantity of air traversing the passage, and the shorter the passage

the more likely is the quantity of air to be small, so that some instrument presenting a longer scale than a water-gauge, would appear to be desirable for properly effecting the object here under notice.

And it would appear to be desirable that, if possible, the same instrument should offer the means of determining the difference of the pressure under which air exists at distant points in an air-way, beyond being applicable to the same purpose, (where an air-way may return upon itself,) in the same manner as the ordinary water-gauge.

(56.) Before proceeding to offer any remarks as to the construction of such an instrument as that just alluded to, let us attend to the following remarks relative to what would be indicated by it—or by an ordinary water-gauge, when made to connect two parts of a connected air-way; as it is believed that some doubts, if not misconceptions, have existed in reference to this.

When any force is added to that by which air or gas is previously compressed, as, for instance, to its barometrical compression; the result of such addition of force to the, previously, stagnant air, will be, that such air will be put into motion, or its degree of compression will be increased, or both of these effects will be produced in a partial degree, according to the circumstances in which the air, or gas, is placed, and the manner in which the force is applied.

If the air or gas were confined in a close vessel, no motion of the air, in the ordinary sense, would be produced, but its compression would be increased to the extent of the force applied.

If, however, the air to which such force was applied, were at liberty to move in a passage or air-way, only open at the ends; on applying the force a general motion of the air would be produced towards the opposite end of the air-way to that at which the force was applied, and, at the same time, some additional compression of the air would result, having its maximum amount at that end of the air-way to which the force was applied, and gradually diminishing in amount towards the contrary end; one portion of the force applied would produce motion alone, while the remainder of the force would only produce additional compression of the air, and no motion; so that the entire amount of applied force admits of being resolved into two parts; one as being equal to a force which would have produced the same amount of motion had the air been free to move unresisted, (except by its own inertia,) under its influence, instead of being confined to an air-way offering frictional and perhaps other resistances to its motion; while the other, or remaining part of the pressure,

or force, would, where its maximum amount prevails, be exactly equal to the whole of the resistances presented to it by the entire extent of the air-way; and the sum of these two forces, would, of course, be exactly equal to the total force applied; the additional compression produced in the air, in any other part of the air-way, would be exactly equal to the resistances offered by the remaining part of the air-way, traversed by the air after passing such point; because motion, and not compression, would be the result of the applied force, except in so far as resistances existed, to offer the necessary re-action to compression; so that the air, at the end of the air-way where the force is applied, would be compressed by the pressure due to the whole of the resistances existing in the entire length of the air-way, and also by the pressure required to create the final velocity with which the air leaves the exit end of such air-way, or, in fact, by the entire force applied, but reduced by the portion due to the velocity of the air at the point where it is applied; and this additional compression of the air would be found to decrease in amount as we followed its course through the air-way, by the exact measure of the pressure due to the resistances overcome in the parts of the air-way so traversed, so long as the sectional area, and consequent velocity of the air, remained the same; the amount of this additional compression would, at each respective part of the air-way, be reduced by the pressure absorbed in creating additional velocity of the air, in such parts as might have less area of section than that part at the outset; and the additional compression would be increased by any amount of pressure arising from an increased area of section and consequent reduction of velocity, and therefore of the pressure absorbed by it; and at the final or exit end of the air-way, the compression of the flowing air will not be at all increased over that of the medium into which it is discharged; the motion of the escaping air absorbing the whole of the remaining force at this part of the air-way, seeing that, except in so far as resistances exist or are encountered, to prevent motion, the whole of the applied force must result in the production of motion only.

(57.) The excess of the force applied, over that which is expended on the resistances of the air-way, would have been sufficient to generate a continually increasing velocity in the air, had such increased velocity not been attended with an increased resistance, and had it really been applied to one and the same body of air, as in the case of a force applied to a solid body; but, in fact, such excess is employed in generating motion in new and distinct quantities of air every moment, and not in

overcoming frictional or other resistances of the like nature, in the case of mines.

(58.) It is necessary to notice, particularly, that we have here been speaking, not of the absolute compression of the air in an air-way, but of the *additional* compression resulting from the application of a force producing motion in air previously acted upon only by forces which are equal in all directions, and so producing no motion in any direction; because, if we commence at the end of an air-way at which such force is applied, and traverse it in the direction pursued by the current of air, the absolute compression of the air as we proceed may increase or decrease to any extent, if the axis of the air-way is not all situated in the same horizontal plane, all descents tending to increase the barometrical compression of the air, and all ascents having the opposite tendency; notwithstanding which, the effect of the additional force being applied, will have resulted in increasing the barometrical compression of the air in each respective part of the air-way, beyond its amount in the same part of the air-way before such force was applied, to the exact amount of the resistances encountered (owing to the motion resulting from its application), in all the subsequent parts of the air-way, including that due to the generation of the final velocity with which the air is ejected from the exit end of the air-way, but reduced by that portion which, at the point of observation, is absorbed by the motion or velocity of the air at the point itself; and the gradual loss of this excess of pressure in traversing an air-way, will at each point be the measure of the resistances, as due to the quantity of air passing, encountered in the preceding parts of the air-way. The loss of absolute barometrical pressure, where it occurs in traversing an air-way in the direction pursued by the air, will evidently embrace, as well as the resistances already alluded to, that which is due to the ascents in the air-way, or, in other words, the force necessary to overcome the gravitation of the air, in all the ascending parts of the air-way which have been traversed, reduced however in amount by the descents, or by the gravitation of the air in all the descending parts of the air-way, whether such ascents or descents are vertical or inclined—the gravitation of the air being calculated as due to the amount of vertical ascent or descent, at its actual density in each part. But when, on the other hand, we find that in going from one point in the air-way to another point nearer to its exit end, the absolute barometrical compression, instead of being less, is actually greater than the pressure at the former point, we must conclude that the gravitation of the air, in the

intervening descending parts of the air-way, exceeds the gravitation of the air in the intervening ascending parts of the air-way, and that, by an amount representing a greater pressure than that which has been expended upon the intervening resistances, due to friction, angles, &c., and even including any expenditure of pressure due to the generation of a higher velocity at the second than at the first point, where an increase of velocity arises simply from the area of the section of the moving air being less at the second than at the first point.

(59.) As the pressures arising from ascending and descending parts of air-ways, do not, like the pressure due to frictional resistances, vary as the square of the quantity of air circulating in a given time through the same air-way, any such pressures will require a distinct and separate consideration in all our investigations, where they may exist; the amount of any such pressures, whether on the whole assisting or retarding the circulation of air, will easily be determined by calculating the pressure due to gravitation in all the ascending parts of an air-way, and the contrary pressure, due to the same source, in all the descending parts of an air-way, by observations on the temperature and barometrical compression of the air in each part, together with a knowledge of the levels of the air-way.

(60.) The principles last alluded to, lead to the conclusion that if we had sufficiently sensitive instruments wherewith to observe with readiness and accuracy the amount of minute differences of barometrical pressure, as prevailing in different parts of an air-way, in which an observed quantity of air is circulating at the time of ascertaining such differences of pressure, we could, (by separating from the observed differences of pressure, the pressures arising from the gravitation of the air in the ascending and descending parts of the air-way intervening between the points of observation, and allowing, if necessary, for different amounts of pressure absorbed, or rendered latent, so to speak, by the velocities of the current at the two points of observation,) ascertain the precise amount of pressure expended upon the resistances due to friction and angles or turnings in the intervening air-way; which resistances, as also those due to the generation of velocity, being proportional to the square of the quantity of air circulating in a given time, in the same air-way, would only require to be divided by the square of the quantity of air circulating in the unit time, at the time of the observations, to give the specific resistance of the intervening air-way, as due to the unit of air circulating in the unit of time, and this may embrace the pressures due to velocity, or

not, as may be desired, and such specific resistance being multiplied by the square of any other quantity of air, would give the pressure required to overcome the same *kinds of resistances* in the same passage, as due to the circulation of that quantity of air through it, per minute, or other unit of time made use of.

(61.) In order more clearly to show what will, in the remainder of this memoir, be intended by the term *specific resistance* of an air-way or mine, let it be presumed that in the case of Hetton Colliery, as alluded to in Table 6, there existed no sources of natural ventilation, or that the air-ways were either all situated in the same horizontal plane, or any ascents or descents were traversed by air of the same density, then in the 1st case there cited, we have, from columns *C* and *G*, a specific resistance of ·000,000,002,584,4 and in the 2nd case this specific resistance appears to be ·000,000,002,533,3, found by the proportions.

	Cubic Feet.		Lineal Feet.		Cub. Ft.		
As	$211{,}193^2$	:	115·27	::	1^2	:	·000,000,002,584,4

and

As	$225{,}176^2$	:	128·45	::	1^2	:	·000,000,002,533,3

as due to the workings only, exclusive of the shafts, &c., the difference in the two cases being about 2 per cent., an amount so small that it might arise either from errors of observation, or from the existence of natural sources of ventilation, not varying with the square of the quantity of air in circulation.

By a similar proportion we will find that the resistances in the workings only, of the example mine alluded to in Tables 2 and 3, exclusive of those of the shafts and undivided air-ways near them, are such as to give, when divided into 5 equal splits, a specific resistance, amounting to ·000,000,029,999, or about 12 times as great as in the case of Hetton Colliery, already cited.

(62.) By employing sufficiently sensitive instruments we could evidently determine the specific resistance of any given air-way, part of an air-way, or series of connected air-ways, or even of the entire workings of a mine, quite independent of the quantity of air circulating at the time, which might be greater or less, depending upon the energy of the furnace or ventilating power employed at the time of observation, and so be able to detect and measure the amount of any improvement or obstruction which from time to time might occur in the same.

If, for instance, after having observed simultaneously the difference of barometrical compression, under which the air existed at the two extreme ends of any air-way, or part of an air-way, to which our observations

might be confined, and also the quantity of air circulating at the time of observation, together with the amount of pressure arising out of the gravitation of the air in the different ascending and descending parts of the air-way, where any such exist; we found that the specific resistance derived from calculations based upon these observations, amounted to a greater or less quantity than we had found by a similar series of observations, at some earlier period, we would be certain that in the former case, the air-ways were either in a worse condition or more extensive than before, and in the latter, that obstructions had been removed, or the run of the air shortened so as to lessen the specific resistances.

This, however, is but one of the uses to which the means of readily and correctly determining the differences of barometrical compression of small amount, existing in different parts of an air-way, might be applicable, because, as has already been observed, if by means of a series of such observations, taken in suitable parts of the air-ways of a mine, we determined the specific resistances of each of the intervening parts of the air-ways, we would be enabled to calculate the quantities of air which would circulate in each split, after any proposed change of air, and, in fact, be able to choose that particular arrangement out of any number of possible or convenient ones, which might be calculated to give the most satisfactory results as to ventilation.

(63.) Applying the principle, that force can only produce compression in so far as resistance to motion exists, and that motion can only ensue in so far as the applied force is not employed in overcoming resistances, to the elucidation of the meaning of the displacement of the pressure-gauge, connecting two points of an air-way, or of the differences of barometrical compression between such two points; and for the present confining our attention to that portion of the air-way extending from what we shall term the 1st point of observation, being that end of the air-way first reached by the current; to the 2nd point of observation or the end of the air-way, or portion of air-way, reached by the current only after traversing the whole of the air-way, or portion of air-way, under consideration; we will perceive that any excess of barometrical compression of the air, at the first, over that which prevails at the second point of observation, will be composed of the following positive pressures—

1st. That which is required to overcome the resistances arising from friction, angles, &c., in the air-way extending to the second point of observation from the first point.

2nd. This excess at the first point will be enhanced by the pressure

required to overcome the gravitation of the air in all the ascending parts of the air-way extending between the two points of observation.

3rd. The excess of pressure at the first over that at the second point of observation, will further be increased by the entire pressure required to generate the velocity of the air at the second point of observation.

But the excess at the first over that at the second point of observation will be reduced in amount by the following causes, to the extent of each :—

1st. The gravitation of the air in all the descending parts of the air-way extending from the first to the second point of observation, as these will tend to increase the compression at the second point of observation, or to overcome resistances, or generate velocity in the air, being, in fact, a source of pressure in favour of ventilation.

2nd. By the force resulting, not in producing pressure, but motion at the first point of observation, being the entire pressure due to the velocity at that point.

It will be perceived that when the forces just named as tending to reduce the excess of pressure at the first over that at the second point of observation, happen to exceed in amount the pressures or forces tending to increase such excess, the result will be that the barometrical compression at the first point of observation will be less than that at the second point of observation; and if the two points are so situated as to admit of being connected by a water or other pressure-gauge of a similar character, the fluid will be depressed on the side exposed to the second, and elevated towards the side exposed to the first point of observation.

In general, however, when speaking of the indications of the gauge being increased, it must be understood to imply an increase in the depression of the fluid exposed to the air at the first point of observation, and in the elevation of that exposed to the second point of observation; and in calculations, when the pressure at the first point of observation happens to be less than at the second point of observation, if we merely change the sign of the displacement from positive to negative, the formula will apply as before.

(64.) That a change of velocity in the air at the second, from that existing at the first point of observation, does, as has been stated, give rise to changes in the barometrical compression of the air, requiring consideration when estimating the indications of the gauge, resistances,

&c., may perhaps appear from considering that when the velocity of the air at the second point of observation exceeds that prevailing at the first point, then, since the pressure required to generate the increase of velocity must have acted in compressing the air at the first point of observation, or the entrance side of the gauge, while, from the increased velocity at the second point having ensued, such force, at that point, no longer produces compression—for the same force cannot result in both motion and compression at the same time—so that the force producing the increase of velocity will not produce any pressure at the second point of observation, and consequently the barometrical differences or displacement of the gauge fluid, as the case may be, if positive, will be increased by the force due to such increase of velocity, or decreased to the same extent, if negative.

On the other hand, when the velocity at the second point of observation is less than the velocity at the first point of observation, it follows that the positive indications of a gauge connecting the two points, or, what is the same, the excess of barometrical compression at the first, over that at the second point of observation, will be less than the real amount due to the other causes affecting it, by the excess of the pressure due to the velocity at the first point of observation over that at the second point; because the amount of force due to such excess will have been given out as the velocity became reduced, in the form of momentum of the air, carrying it over resistances encountered in the air-way lying between the points of observation, although it would not have existed as observable pressure at the first point; it being, so to speak, rendered latent, or resulting only in motion at that point. When the indication of the gauge is negative, or when the barometrical compression of the air is less at the first than at the second point of observation, the amount of negative indications will be increased from the cause under consideration.

(65.) Adopting the following notation :—

D_0=the height required in an air-column of some standard density, (say that of the average of the air in the downcast shaft,) so that the pressure per unit of surface of area, produced by its weight, may be exactly equal to that produced by the actual downcast column of air, on equal areas; including, in such downcast column, the depth of the downcast shaft, and also, (when the top of the upcast shaft is situated at a higher level than the top of the downcast shaft,) the column of air extending upwards, from the

top of the downcast shaft to the level of the top of the upcast shaft.

U_0=the length in feet, required in a vertical column of air, of the density adopted as a standard, that it may be capable, by its weight, of producing a pressure equal to that arising from the upcast column of air, on equal areas; including, in the upcast column, not only the air in the upcast shaft, but also, (when the top of the downcast shaft happens to be situated at a higher level than the top of the upcast,) the column of air extending upwards, from the top of the upcast shaft to the level of the top of the downcast shaft.

D_1=the head of air-column, of standard density, equal to the production of pressure, of the same amount on equal areas, as that arising from all the descending parts of the air-way extending from the bottom of the downcast shaft to the first point of observation.

U_1=the head of air-column, of standard density, due to the ascending parts of the air-way extending from the bottom of the downcast shaft to the first point of observation.

D_2=the head of air-column, due to the pressures arising from the gravitation of the air in the descending parts of the air-way, extending from the first point to the second point of observation.

U_2=the head of air-column, of standard density, equal to the pressure arising from the gravitation of the air in the ascending parts of the air-way extending from the first to the second point of observation.

D_3=the head of air-column, of standard density, capable of producing, by its weight, a pressure on equal areas, of the same amount as that due to the gravitation of the air in the descending parts of the air-way extending from the second point of observation to the bottom of the upcast shaft.

U_3=the head of air-column, of standard density, capable of producing, by its weight, a pressure of the same amount, on equal areas, with that arising from the gravitation of the air in all the ascending parts of the air-way extending from the second point of observation to the bottom of the upcast shaft.

The descents and ascents, in all the preceding cases, being reckoned as they occur in the *direction pursued by the circulating current of air.*

The 1st point of observation must be considered as existing at the point where an unventilated gallery in which a pressure gauge is fixed,

joins the air-way on the side nearest to the downcast shaft; and the 2nd point of observation must be considered as situated at the point where the opposite end of such unventilated passage joins the air-way, on the side nearest to the upcast shaft, in all cases where the gauge is used, in the ordinary way, by being inserted in a stopping or door situated in such a passage, extending from the 1st to the 2nd point of observation; and the areas and velocities, with the pressures required to generate them, must accordingly be taken as they exist at these respective points:—and the pressure due to the gravitation of the air in ascending and descending parts of the air-way, must, on the same principle, be considered only as they happen to exist in the air-way itself, as these arising from the gravitation of the air in ascents and descents occurring in the unventilated passage, although they will act upon the gauge, will not affect the pressure required to circulate the air; and hence, when a gauge is used in such a passage, its indications will require to be corrected for the effects which may arise from this source, in order to arrive at the real difference of pressure between the air at the 1st, and that at the 2nd point of observation: this will be effected by deducting from any excess of pressure indicated by the gauge, as existing on the side next to the 1st, over that existing on the side next to the 2nd point of observation, the pressure arising from the gravitation of the air in the descents which occur in traversing the unventilated passage from the 1st towards the 2nd point of observation; and by adding to such indicated excess, the pressure due to the gravitation of air in all the ascents occurring in the same direction, throughout the entire length of the passage. When the gauge indicates an excess of pressure in favor of the side exposed to the 2nd point of observation, it will, of course, be necessary to correct its indications by adding for the descents, and deducting for the ascents, reckoned as they occur in such passage, in the direction from the 1st towards the 2nd point of observation. Where no such unventilated passage connects the two points of observation, or is not made use of in determining the difference of pressure between the two points, of course the corrections indicated above do not require to be made.

p_1 = The height of air column, of the density taken as a standard, required to overcome the resistances due to friction, contractions, or angles, in the downcast shaft.

p_2 = The height of air column, of standard density, due to the resistances of the same character, in the air-way extending from the downcast shaft to the 1st point of observation.

P = The head of air column of standard density, required to overcome the resistances due to friction, angles, &c., in the portion of air-way under notice, extending from the 1st to the 2nd point of observation.

p_3 = The head of air column required to overcome the same resistances, in the air-ways extending from the 2nd point of observation to the bottom of the upcast shaft.

p_4 = The head of air column due to the resistances of the same character, in the upcast shaft.

a_1 = The area in superficial feet, of the air-way at the 1st point of observation.

a_2 = The area in superficial feet, of the air-way at the 2nd point of observation.

A = The area in feet, at the top of the upcast shaft.

B = The head of air column, of standard density, due to the barometrical pressure at the top of the upcast or downcast shaft; that is, at the top of the shaft, situated at the highest level.

Q = The cubic feet of air per minute, circulating through the portion of air-way lying between the two points of observation; the same quantity of air being presumed to be passing each of the two points of observation.

According to what is stated in (63), we shall have for the excess of pressure at the first point of observation, over that existing at the 2nd point of observation,—and when the negative parts exceed the amount of the positive parts of the expression, the excess will indicate the pressure by which the air at the 2nd point of observation, exceeds in compression, that at the 1st point of observation :—

$$P + U_2 + \frac{Q^2}{231600\, a_2^2} - D_2 - \frac{Q^2}{231600\, a_1^2} \ldots\ldots\ldots\ldots [96]$$

(66.) By the same mode of reasoning we find that the absolute barometrical compression of the air at the first point of observation will consist of,—

1st. The barometrical compression of the air at the top of the higher of the two pit tops, the upcast or the downcast.

2nd. The gravitation of the air in the downcast shaft.

3rd. The gravitation of the air in the descending parts of the air-way extending from the bottom of the downcast shaft to the first point of observation.

The sum of the above would however require to be reduced by,

1st. The resistances of a frictional character, angles, and contractions, in the downcast shaft.

2nd. The same kind of resistances in the air-ways extending from the bottom of the downcast shaft to the first point of observation.

3rd. The gravitation of the air in all the ascending parts of the air-way, from the bottom of the downcast shaft to the first point of observation.

4th. The pressure absorbed by, or resulting in, the production of motion at the first point of observation; it being supposed to start from a state of rest at the top of the downcast shaft.

The pressure at the first point of observation will therefore be expressed by,

$$B + D_0 + D_1 - p_1 - p_2 - U_1 - \frac{Q^2}{231600\, a_1^2} \quad \ldots\ldots\ldots\ldots\ldots [97]$$

(67.) By considering the same principles which have been recited and applied to determine the expressions [96] and [97]; but in the opposite direction, commencing at the top of the upcast shaft; we shall have for the absolute barometrical compression of the air at the second point of observation;—

1st. The barometrical compression of the air at the level of the top of the higher of the two pit tops.

2nd. The pressure, in an air-column of standard density, due to the upcast column of air, from the level of the plane in which the higher of the two pit tops is situated, to the bottom of the upcast shaft.

3rd. The pressure in an air-column, equal to the gravitation of the air in all the ascents made by it, in the air-ways extending from the second point of observation to the bottom of the upcast shaft.

4th. The air-column due to all the resistances in the air-way extending from the 2nd point of observation to the bottom of the upcast shaft.

5th. The air-column due to the resistances in the upcast shaft.

6th. The air-column due to the final velocity at the top of the upcast shaft.

But reductions will require making, for,

1st. The velocity of the air at the second point of observation.

2nd. The gravitation of the air in all the descending parts of the air way traversed by the air after passing the second point of observation, and before reaching the bottom of the upcast shaft.

This absolute pressure of the air at the second point of observation, will therefore be expressed by,

$$B + U_0 + U_3 + p_3 + p_4 + \frac{Q^2}{231600\,A^2} - \frac{Q^2}{231600\,a_2^2} - D_3 \;\ldots\; [98]$$

(68.) The difference found by deducting this pressure at the second point of observation, from that already found as existing at the first point of observation, should leave the excess of pressure, (the same as [96]), at the first, over that at the second point of observation; the difference in question, found by deducting [98] from [97], is

$$D_0 + D_1 - p_1 - p_2 - U_1 - \frac{Q^2}{231600\,a_1^2} - U_0 - U_3 - p_3 - p_4$$
$$- \frac{Q^2}{231600\,A^2} + \frac{Q^2}{231600\,a_2^2} + D_3 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [99]$$

And this expression is, as above stated, equal to [96], or,

$$D_0 + D_1 - p_1 - p_2 - U_1 - \frac{Q^2}{231600\,a_1^2} - U_0 - U_3 - p_3 - p_4 - \frac{Q^2}{231600\,A^2} +$$
$$\frac{Q^2}{231600\,a_2^2} + D_3 = P + U_2 + \frac{Q^2}{231600\,a_2^2} - D_2 - \frac{Q^2}{231600\,a_1^2} \;\ldots [100]$$

from whence we derive the equation,

$$(D_0 + D_1 + D_2 + D_3) = (U_0 + U_1 + U_2 + U_3) + p_1 + p_2 + P +$$
$$p_3 + p_4 + \frac{Q^2}{231600\,A^2} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [101]$$

An equation shewing that the pressure arising from all the descending columns of air, is exactly equal to the total expenditure of pressure employed in overcoming the gravitation of all the ascending columns of air, together with the frictional resistances in the shafts and air-ways, and in finally ejecting the air from the top of the upcast shaft; when the air has been presumed to commence from a state of rest at the top of the downcast shaft: an equation which strongly indicates the correctness of the reasoning which has been followed in obtaining it.

(69.) On examining [96], which expresses the excess of pressure at the 1st point of observation, over that existing at the 2nd point of observation, it will be seen, that when the excess is positive, and $P + U_2 + \frac{Q^2}{231600\,a_2^2}$ really exceeds the negative part of the expression $D_2 + \frac{Q^2}{231600\,a_1^2}$, the displacement of the gauge fluid, or difference of pressure between the two points of observation, will be an exact measure *of the excess of the resistances arising from friction, angles, and contractions, together with*

the pressure required to overcome the gravitation of the air in the ascending parts of the air-way lying between the two points of observation, and to generate the velocity with which the air is driven past the 2nd point of observation, over the pressure arising from *the gravitation of the air in the descending parts of the air-way lying between the 1st and 2nd points of observation, added to the pressure due to the generation of the velocity with which the air reaches the 1st point of observation:*— in other words, the difference of pressure between the two points of observation, when positive, in favor of the 1st point of observation, is an indication *of the excess of expenditure of pressure, in the air-way extending from the 1st to the 2nd point of observation, upon resistances and motion,* over that arising in the same part of the air-way, both from *the pressure due to the initial velocity with which the air enters upon it, and from the gravitation of the air in favor of ventilation, in the descending parts of the air-way itself.*

(70.) When the excess is in favor of the 2nd point of observation, the negative indications of the gauge, or barometrical differences, will, on the other hand, be an exact measure *of the excess of the pressure or momentum, due to the initial velocity, and the gravitation of the air in the descending parts of the air-way lying between the 1st and 2nd point of observation,* over the expenditure of pressure in the same part of the air-way, both upon *the resistances of friction, angles, and contractions, and also upon propelling the air up the ascending parts of such air-way, and finally ejecting it into the air-way lying beyond the 2nd point of observation.*

(71.) The foregoing is an explanation of the indications of a pressure-gauge, as to the differences of pressure existing at any two points in an air-way, in reference to the air-way lying between the points only. In order to see the meaning of these indications, in reference to the shafts and the other portions of the air-ways, extending from the bottom of the downcast shaft to the first point of observation, and from the second point of observation to the bottom of the upcast shaft, it is only necessary to examine [99], which is an expression of the same value as [96], which we have just been considering; each representing the difference of pressure between the two points of observation.

The positive items in [99] consist of

$$D_0 + D_1 + D_3 + \frac{Q^2}{231600\, a_2^2}$$

and the negative items of

$$p_1 + p_2 + p_3 + p_4 + U_0 + U_1 + U_3 + \frac{Q^2}{231600\, a_1^2} + \frac{Q^2}{231600\, A^2}$$

and when the difference of pressure between the two points is positive, in favour of the first point of observation, the former exceed the latter, the pressure indicated being, in fact, an exact measure of the excess of force or pressure arising *in the descending parts of the shafts, and air-ways lying between them and the points of observation, together with that due to the velocity with which the air enters upon that portion of such air-ways which extend outwards from the second point of observation towards the bottom of the upcast shaft,* over that which is due to *the resistances of friction, angles, and contractions, and to the gravitation of the air in all the ascending parts, of the downcast shaft, and air-ways extending from it to the first point of observation; and also in those extending from the second to the upcast shaft, and in the upcast shaft itself; together with the expenditure of pressure on ejecting the air from the air-way, at the first point of observation, into the air-way lying between the two points of observation, and again into the atmosphere at the top of the upcast shaft.* The descents and ascents being reckoned as they occur in the *direction in which the current of air flows,* the air being supposed to enter the downcast shaft from a state of rest; because, if the air entered the downcast shaft with a velocity arising from winds, the pressure due to its generation would require to be added to the positive parts of the expression.

(72.) When the pressure is greater at the second than at the first point of observation, the indications of a gauge will be negative, and the excess of pressure indicated will be a measure of the *excess of the pressure due to friction, angles, and contractions, and expended on overcoming the gravitation of the air, in the ascending parts, of the downcast shaft and the air-ways extending from it to the first point of observation, and in those extending from the second point of observation to the bottom of the upcast shaft, and also in the upcast shaft itself; together with the expenditure of pressure on creating both the velocity at the first point of observation, and also that with which the air leaves the top of the upcast shaft,* over the pressures due to or arising from *the gravitation of the air in the descending parts of the shafts and air-ways above alluded to, together with that arising from the momentum with which the air enters upon the air-way extending from the second point of observation outwards, to the bottom of the upcast shaft.*

(73.) In general terms the indications of pressure given by a water or

other similar pressure-gauge connecting the two points of observation, (after being corrected, if necessary, for the gravitation of the air, in any ascents and descents in an unventilated passage, wherein it is fixed,) have the same meaning and amount as the differences of barometical pressure of the air at the two points of observation, of which they are the true measure; and when the excess prevails at the first point of observation, which will always be the case when the intermediate air-ways are horizontal, *this excess is equal to the excess of the force or pressure expended, over that generated or arising, in the air-ways extending from the first to the second point of observation;* and, at the same time, it is a measure of *the excess of force or pressure arising, over that which is expended, in the shafts and other air-ways lying between them and the points of observation.* But, on the contrary, when it happens that the excess indicated is in favour of the second point of observation, or what may be termed negative, then it is a measure of *the excess of the force or pressure arising or generated, over that which is expended, in the air-ways lying between the points of observation;* and, at the same time, it is also a correct indication of *the excess of the force or pressure expended, over that which arises or is generated, in the shafts and in the air-ways extending between them and the respective points of observation.*

Having now determined the real meaning or indications denoted by the displacement of a gauge fluid, or by the differences of barometrical pressures existing in different parts of an air-way, whether such excess exists at the first or at the second point of observation; and that, both in reference to the air-ways lying between the two points of observation, and again, in reference to the shafts, and the other or remaining air-ways, extending from them to the respective points of observation, we shall proceed to make some general remarks on the qualities required in instruments for determining the quantities of air, and also in those for determining the differences of barometrical pressure, regretting, however, that good instruments, for the latter purpose in particular, still appear to remain a desideratum, rather than a thing which has been realized—even after the remarks and suggestions about to be offered.

other similar pressure-gauge connecting the two points of observation, (after being corrected, if necessary, for the gravitation of the air, in any ascents and descents in an unventilated passage, wherein it is fixed,) have the same meaning and amount as the differences of barometical pressure of the air at the two points of observation, of which they are the true measure; and when the excess prevails at the first point of observation, which will always be the case when the intermediate air-ways are horizontal, *this excess is equal to the excess of the force or pressure expended, over that generated or arising, in the air-ways extending from the first to the second point of observation;* and, at the same time, it is a measure of *the excess of force or pressure arising, over that which is expended, in the shafts and other air-ways lying between them and the points of observation.* But, on the contrary, when it happens that the excess indicated is in favour of the second point of observation, or what may be termed negative, then it is a measure of *the excess of the force or pressure arising or generated, over that which is expended, in the air-ways lying between the points of observation;* and, at the same time, it is also a correct indication of *the excess of the force or pressure expended, over that which arises or is generated, in the shafts and in the air-ways extending between them and the respective points of observation.*

Having now determined the real meaning or indications denoted by the displacement of a gauge fluid, or by the differences of barometrical pressures existing in different parts of an air-way, whether such excess exists at the first or at the second point of observation; and that, both in reference to the air-ways lying between the two points of observation, and again, in reference to the shafts, and the other or remaining air-ways, extending from them to the respective points of observation, we shall proceed to make some general remarks on the qualities required in instruments for determining the quantities of air, and also in those for determining the differences of barometrical pressure, regretting, however, that good instruments, for the latter purpose in particular, still appear to remain a desideratum, rather than a thing which has been realized—even after the remarks and suggestions about to be offered.

$$p_1 + p_2 + p_3 + p_4 + U_0 + U_1 + U_3 + \frac{Q^2}{231600\,a_1^2} + \frac{Q^2}{231600\,A^2}$$

and when the difference of pressure between the two points is positive, in favour of the first point of observation, the former exceed the latter, the pressure indicated being, in fact, an exact measure of the excess of force or pressure arising *in the descending parts of the shafts, and air-ways lying between them and the points of observation, together with that due to the velocity with which the air enters upon that portion of such air-ways which extend outwards from the second point of observation towards the bottom of the upcast shaft,* over that which is due to *the resistances of friction, angles, and contractions, and to the gravitation of the air in all the ascending parts, of the downcast shaft, and air-ways extending from it to the first point of observation; and also in those extending from the second to the upcast shaft, and in the upcast shaft itself; together with the expenditure of pressure on ejecting the air from the air-way, at the first point of observation, into the air-way lying between the two points of observation, and again into the atmosphere at the top of the upcast shaft.* The descents and ascents being reckoned as they occur in the *direction in which the current of air flows,* the air being supposed to enter the downcast shaft from a state of rest; because, if the air entered the downcast shaft with a velocity arising from winds, the pressure due to its generation would require to be added to the positive parts of the expression.

(72.) When the pressure is greater at the second than at the first point of observation, the indications of a gauge will be negative, and the excess of pressure indicated will be a measure of the *excess of the pressure due to friction, angles, and contractions, and expended on overcoming the gravitation of the air, in the ascending parts, of the downcast shaft and the air-ways extending from it to the first point of observation, and in those extending from the second point of observation to the bottom of the upcast shaft, and also in the upcast shaft itself; together with the expenditure of pressure on creating both the velocity at the first point of observation, and also that with which the air leaves the top of the upcast shaft,* over the pressures due to or arising from *the gravitation of the air in the descending parts of the shafts and air-ways above alluded to, together with that arising from the momentum with which the air enters upon the air-way extending from the second point of observation outwards, to the bottom of the upcast shaft.*

(73.) In general terms the indications of pressure given by a water or

other similar pressure-gauge connecting the two points of observation, (after being corrected, if necessary, for the gravitation of the air, in any ascents and descents in an unventilated passage, wherein it is fixed,) have the same meaning and amount as the differences of barometical pressure of the air at the two points of observation, of which they are the true measure; and when the excess prevails at the first point of observation, which will always be the case when the intermediate air-ways are horizontal, *this excess is equal to the excess of the force or pressure expended, over that generated or arising, in the air-ways extending from the first to the second point of observation*; and, at the same time, it is a measure of *the excess of force or pressure arising, over that which is expended, in the shafts and other air-ways lying between them and the points of observation.* But, on the contrary, when it happens that the excess indicated is in favour of the second point of observation, or what may be termed negative, then it is a measure of *the excess of the force or pressure arising or generated, over that which is expended, in the air-ways lying between the points of observation;* and, at the same time, it is also a correct indication of *the excess of the force or pressure expended, over that which arises or is generated, in the shafts and in the air-ways extending between them and the respective points of observation.*

Having now determined the real meaning or indications denoted by the displacement of a gauge fluid, or by the differences of barometrical pressures existing in different parts of an air-way, whether such excess exists at the first or at the second point of observation; and that, both in reference to the air-ways lying between the two points of observation, and again, in reference to the shafts, and the other or remaining air-ways, extending from them to the respective points of observation, we shall proceed to make some general remarks on the qualities required in instruments for determining the quantities of air, and also in those for determining the differences of barometrical pressure, regretting, however, that good instruments, for the latter purpose in particular, still appear to remain a desideratum, rather than a thing which has been realized—even after the remarks and suggestions about to be offered.

CHAPTER VII.

Remarks on certain Instruments used for taking Observations relating to the Ventilation of Mines—Formulæ for converting Pressures—Table of the Tension of Aqueous Vapour.

(74.) The anemometer of Mr. Biram, which is now much used for measuring the velocity of currents of air in mines, like that of Mr. Combes, is, when well constructed, a very useful instrument. These instruments, however, are affected by friction, so that the number of revolutions in a given time are not proportional to the velocity of the air; and, in fact, are so much affected by it, that in slow currents they may not revolve at all, and become inapplicable in consequence.

The velocity of any current of air, acting upon either of these instruments, will be determined by the use of a formula, of the form of

$$v = a + bn \quad \ldots\ldots\ldots\ldots\ldots\ldots [102]$$

where $v =$ the velocity of the current of air, and a and b are constants, suited to the particular instrument; for, although they are different in different instruments, yet are they each constant, for the same instrument, whatever may be the velocity of the current.

The constants a and b can be determined for any instrument by means of two experimental trials of the number of revolutions corresponding to different velocities: thus if v and n are the velocity, and corresponding revolutions in a unit of time, in one of such trials; and v' and n' the same, respectively, in the other trial; then, since

$$v = a + bn$$
$$\text{and } v' = a + bn'$$

it follows that,

$$b = \frac{v - v'}{n - n'} \quad \ldots\ldots\ldots\ldots\ldots\ldots [103]$$

and

$$a = \frac{n' v - nv'}{n' - n} \quad \ldots\ldots\ldots\ldots\ldots\ldots [104]$$

In these experiments, instead of exposing the instrument to moving air, the air may be still, and the instrument itself put in motion, at some determinate velocity, by machinery; this is the mode pursued on the Continent in constructing the anemometer of Mons. Combes; the values of the constants a and b being furnished to the purchaser of each instrument.

Whenever the velocity is less than the constant a, these instruments do not revolve, and cannot be used for determining the velocity of a current of air in consequence.

(75.) The anemometer of Dr. Lind is very similar in construction to an ordinary water-gauge, but has a wide mouth-piece attached to one of the vertical limbs of the U shaped tube, to receive the impact of the current of air; and the force of the wind is measured by the difference of the level of the water, in the two branches of the tube; the undulations of the water being, to some extent, reduced by a contracted portion of tube, which connects the two vertical branches.

This instrument is good in principle, as it is not affected by friction, and is easily applied to determine the force of winds, whether horizontal, vertical, or inclined, in the direction of their motion; and that without involving any measurement of time, as the velocity can be calculated directly from the force or impact of the air; the instrument, however, will seldom apply to such currents as exist in mines, it not being sufficiently sensitive; a velocity of 1 foot per second, or 60 feet per minute, would only give a displacement of 1-2,756th part of an inch in the water-column; and even 4 feet per second, or 240 feet per minute, would only produce a displacement of 1-172nd part of an inch of water-column; while a velocity of current equal to 1,000 feet per minute, such as prevails in some upcast shafts, would only produce a pressure of about one-tenth of an inch of water-column; the mere variations in velocity, being indicated by variations in so short a column, would, of course, be scarcely discernable on the scale of such an instrument.

(76.) The loss of pressure due to the resistances offered by the air-ways of a mine has frequently, of late years, been determined by the use of the now well-known instrument called the water-gauge. The entire resistances of the workings seldom giving a displacement of more than 2 inches of water-column; any slight variations in such a quantity being too small for easy and correct measurement; an evil which again becomes greater, as the portion of air-ways to which it is applied, are of less extent and resistance; and such an instrument is, from its very nature, totally inapplicable to measure the resistance of a mine, when the

shafts are situated at a great distance apart, and are not connected by any unventilated passage, in which to fix the instrument; and it is equally inapplicable to the measurement of the resistances of any air-way, or part of an air-way, the extremities of which are situated at a distance from each other, and not connected by any unventilated passage, containing a separation door or stopping, in which to apply it.

Having paid some attention to this subject, in hopes of devising an instrument which would enable us to observe the resistances of air-ways under all circumstances, I venture to throw out suggestions, which if not satisfactory in all respects, may at any rate be of service to others, who may more successfully attempt the same thing.

(77.) An instrument is named by Dr. Ure, in his "Dictionary of Arts, Manufactures, and Mines," under the article "Chimney," which he ascribes to Wollaston, as being invented by him, to be used as a differential barometer; and which Dr. Ure adopted for measuring the draughts or ventilating power of furnaces.

A modification of this instrument, or what I presume to be such, (for it is only partially described by Dr. Ure, and I have not seen Wollaston's description of it,) would appear to furnish a very sensitive pressure-gauge, to be used instead of the ordinary water-gauge; and might, perhaps, also admit of being applied to measure the loss of pressure due to resistances of air-ways, or portions of air-way, having their extremities totally unconnected by any unventilated gallery.

In Plate 1, figures 1 and 2, let a, b, c, d, represent a metallic air-tight box, with an air-tight diaphragm, e, f, dividing it into two equal parts, communicating with each other by means of the small pipe g, with a stop-cock h in it; the compartment of the vessel e, b, f, d, has a pipe, b, k, with a stop-cock, i, attached to it; and the other compartment of the metallic vessel, a, e, c, f, has a similar pipe, m, a, with a stop-cock, l, attached to it. A brass or copper tube, q, p, o, w, having a stop-cock at n, is fixed air-tight into the vessel at q; and a glass tube, v, w, is fixed, air-tight, into the tube at w; and its opposite end is similarly fixed into the other compartment of the vessel at v. The two side tubes are "*screwed*" at m, and k. A scale, divided into inches and tenths, is attached to the glass tube: m, g, k, is one continuous tube.

If water, of the specific gravity of 1,000, be introduced through the side tube, k, b; while the cock, n, is kept closed; and if some oil of a pure character, having a known density, not greatly differing from that of water, be introduced through m, a, into the other leg of the bent tube,

and the cock, n, be opened, and more oil or water be added, till the *junction line of the oil and water* stands at, or somewhere above zero, (z), on the scale, then the instrument is ready for use.

To use this instrument as a gauge, in lieu of the ordinary water-gauge, close all the stop-cocks, l, h, i, and n, and attach the instrument, by means of a small gutta percha tube, screwed, or otherwise fixed to k, or m, to a tube inserted in a door or stopping, separating the intake air from the return air; then bring the instrument into a perfectly vertical position, either by having it swung in gimbals, or by means of small spirit levels, attached to, and forming a part of the instrument; and open the cocks n, and h, while i, and l, remain closed; note the part of the scale where the junction of the oil and water rests, and afterwards open the cocks i, and l, and close h, and again note the part of the fixed scale where the junction of the oil and water rests.

The difference of the two observations will furnish the means of determining the difference of pressure, on the two sides of the door or stopping, in which the instrument is used; and hence, also, of the resistances of the air-ways, traversed by the air after passing the intake side of the door or stopping, and before reaching the contrary side of it. The stop-cock, n, will be useful in carrying the instrument, to prevent the oil from getting into the water tube, and so ascending to the top of it; and will, by being only partially opened when the instrument is in use, tend to prevent undulations of the fluids, from temporary disturbances of the pressures to which they are exposed.

Let r = the distance in inches, traversed by the junction line of the oil and water.

a = area of the glass tube, traversed by the junction of oil and water.

A = the area of each of the equal compartments, into which the metallic vessel is divided.

s = specific gravity of the oil used.

S = ... do. .... of the water used.

Then the pressure in inches of water column, arising from the movement of the fluids will be,

In the vertical tube of glass, $r\,(S-s) \div S$;

In the oil compartment, $r\,\frac{a}{A}\,s \div S$;

In the water compartment, $r\,\frac{a}{A}S \div S$.

The entire pressure creating the movement, (being the sum of the above,) will be expressed by

$$G = r\left(\frac{(S-s) + \frac{a}{A}(S+s)}{S}\right) \ldots\ldots\ldots\ldots\ldots [105]$$

where G represents the pressure in inches of water column; and hence,

$$r = \frac{S\,G}{S-s + \frac{a}{A}(S+s)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots [106]$$

so that if we suppose the oil used, to be refined linseed oil, having a specific gravity of 940, that of water being 1,000; and the area of the vessel to be 729 times that of the glass tube, or each compartment to be 364½ times the area of the glass tube; which would be the case if the metallic vessel had a diameter of about 9 inches, while that of the glass tube is taken at ½ of an inch, both the metallic vessel and tube being supposed to be cylindrical, or having circular sections.

Then, an inch of water-gauge would be represented by a rise equal to

$$r = \frac{1000 \times 1}{1000-940 + \frac{1}{364\frac{1}{2}}\ (1000 + 940)} = 15{\cdot}3087$$

inches in such an instrument; so that it would have a scale upwards of 15 times as long as that of a water-gauge, to represent equal pressures.

If, in such an instrument as has just been described, a small vertical strip of glass were cemented into the metallic vessel, so as to shew the height of the surfaces of the oil on one side of the diaphragm, and of the water in the other compartment of the vessel, and if this glass were divided into inches and tenths, in continuation upwards, of the scale before alluded to, it would enable us to determine the relative densities of the oil and water, employed in using the instrument; and would be also serviceable in enabling the actual volume of enclosed air, contained in the vessel, to be ascertained; which will be required if the instrument should be used in the manner hereafter to be explained, for determining the difference of pressure, prevailing at parts of an air-way situated at distances apart from each other, and unconnected by any unventilated air-way, so as to prevent the use of the instrument in the form in which the ordinary water-gauge is used.

Such a strip of glass is represented in the figures by e, f.

To determine the relative specific gravities of any oil and water made use of, it would only be necessary to bring the instrument into a vertical

position, and to open the stop-cocks n and h, allowing those at k and l, to remain closed; and then to observe the point of the scale at or above zero, where the junction of the oil and water rests, and also the two points on the strip of glass, (forming a part of the sides of the upper metallic vessel, and the continuation of the scale upwards,) at which the surfaces of the oil and water, respectively rest. Then by deducting the height of the point of junction of the oil and water, above zero on the scale, from the height of the surface of the water, above the same zero, we shall have the length of water column which is equal to that of an oil column; the height of which will be found, in like manner, by deducting the height from zero of the scale to the line of junction of the oil and water, from the height at which the surface of the oil rests above zero of the scale. The lengths of the columns of water and oil, so found, since they exactly balance each other, will be inversely proportional to the specific gravities of the liquids of which they consist.

If by J, we represent the height above zero, at which the junction of the oil and water rests; by W, the height above the same point, at which the surface of the water rests; and by O, the height, also above the same point, at which the surface of the oil rests; by S, the specific gravity of the water, and by s, that of the oil employed; then,

$$\text{As } S : s :: O - J : W - J$$

and hence the specific gravity of the oil,

$$s = S \frac{W - J}{O - J} \quad \ldots\ldots\ldots\ldots\ldots\ldots [107]$$

In such an instrument as that described, if the length of the glass tube above zero on the scale were $(15{\cdot}3087 \times 2) = 31$ inches, nearly; it would, by using oil of the specific gravity 940, measure a difference of pressure, equal to 2 inches of water-column, and be upwards of 15 times as sensitive as the ordinary water-gauge:—and by using oil of less specific gravity, in an instrument of greater length, of course greater differences of pressure could be determined, with even greater accuracy.

The instrument described might be used after the manner of Lind's anemometer, to measure the velocity of currents of air, by adapting a trumpet-mouthed gutta percha tube to the side tubes, m, or k, to receive the impulse of the wind:—but, for currents of less than 7 feet per second, or 420 feet per minute, it can scarcely be considered sufficiently sensitive; at least the displacement of the line of junction, would, for any such currents, be very small in amount; although it would, where applicable, have the advantage of being unaffected by friction, and not being confined

to horizontal currents, nor requiring the measurement of time; the velocity being deduced directly from the force of the wind, in direct impact; and it would be upwards of 15 times as sensitive as Lind's anemometer, if made of the dimensions before alluded to, and oil of specific gravity 940 were used.

Dr. Ure suggests that by the use of proof spirit, and spermaceti oil, in such instruments; a great degree of sensitiveness may be obtained, as they are so nearly of the same specific gravity. As the water and oil displace each other, by any motion of the point of junction, the actual pressure is represented by a fluid, having a specific gravity only equal to the difference of the specific gravities of the fluids used; at any rate, so far as regards the distance traversed by the point of junction of the water and oil:—there being a reduction to be made from this degree of sensitiveness, owing to the motion of the surfaces of the fluids in the metallic vessel at the top of the instrument just described; but as the areas of the surfaces in question, are, or may be, some hundreds of times greater than the area of the glass tube in which the junction line of the fluids moves, their effects are proportionably reduced.

The contrivance of an instrument of great sensibility for determining the minute differences of absolute barometrical pressure prevailing at two points of an air-way, when such points are not so situated as to admit of the direct measurement of such difference of pressure, either by a water, or other more sensitive pressure-gauge, appears to remain a desideratum.

An instrument intended to effect a similar object to this, recently brought under notice by Mr. Gurney, appears to me to be open to the objection, that, while it requires very great corrections for the effects of heat, its peculiar construction renders it very difficult to apply such corrections.

Another, mentioned by Mr. Mackworth, the Inspector of Mines, is not sufficiently explained in the account which has come under my observation, to warrant me in giving any opinion as to its merits; but such an instrument, seeing that it would be likely to supersede the common barometer, if of a portable character, and free from requiring the application of corrections for heat, leads me to fear that it is objectionable on the same account. Various kinds of contrivances are described in Hutton's Philosophical Dictionary, and other works of a similar character, for increasing the scale on which changes of barometrical pressure are indicated; but all that I have yet seen, and I am sorry to add all that I

can yet imagine, are liable to one or other of the objections, want of portability, or the necessity of very great corrections for the effects of heat.

(78.) As an addition to the general stock of such suggestions or contrivances, I think it worth while noticing the manner in which the instrument to which I have just alluded might be made use of for determining very minute differences of barometrical pressure; and although requiring very great corrections for the effects of heat, it appears to be at least capable of admitting the application of such corrections, with very great nicety. Possibly the suggestion may lead some one else to another, and more effectual mode, of attaining the same object.

In order to determine the difference of barometrical pressure, prevailing at any two points of an air-way, so situated with respect to each other, as not to admit of such difference of pressure being determined by the ordinary use of the water, or differential pressure-gauge; we may proceed as follows:—

Take the oil and water-guage to one of the two points, which we shall distinguish from the other by calling it the first station, or the first point of observation; and fix the instrument in a perfectly vertical position, and after opening the stop-cocks n, l, and i, bring the junction line of the oil and water in the glass tube to a position about half-way up the scale, by introducing or abstracting, oil or water, if found necessary; after allowing the instrument to acquire the temperature of the surrounding air, make and note down the following observations, which we will here denote by the respective letters prefixed to them,—

t° = The temperature of the air at the first station; which may be taken either by a thermometer attached to the instrument, or a separate one.

p = The barometrical pressure of the atmosphere, reduced to inches of water-column; which may be observed either by a sympiesometer, or a mercurial, or aneroid barometer.

b = The number of cubic inches of air existing in the water compartment of the metallic vessel at the top of the instrument. The area of a horizontal section of this compartment being A, it will be necessary, in order to find this, to multiply such area, in inches, by the distance in inches, from the top of the vessel to the surface of the water; which can be observed by means of the scale of inches and parts, to be marked on the strip of glass, fixed vertically into, and forming a part of the side of the vessel.

If the relative specific gravities of the oil and water are not known, it will also be necessary to make a similar observation with reference to the surface of the oil, and by [107], the specific gravity of the oil will be found.

h = The height above zero of the scale, in inches and parts, at which the junction line of the oil and water stands in the glass tube. Previous to making this observation, it would, perhaps, be well, partially to close the stop-cock, i, so as to ensure the enclosed air being saturated with the vapour of the water, due to the existing temperature.

Also let

f = The tension of watery vapour, due to the temperature t°, when saturated; expressed in inches of water-column, which can be found from tables, hereafter to be given—next, gently close the stop-cock, i, so as not to move the junction line of the oil and water in doing so, and also close the stop-cocks, l, and n; and proceed with the instrument, in this state, to the second point of observation; on reaching which, the instrument must be allowed to acquire the temperature of the surrounding air, and then, when in a perfectly vertical position, the stop-cocks, l, and n, must be opened; i and h remaining closed; the air, thus being admitted to the surface of the oil, will allow the confined air over the water, to expand, or cause it to contract, so as to establish an equilibrium of pressures; the amount of such expansion, or contraction, will be found from the movement of the junction line of the oil and water in the glass tube. At the second station it will be necessary to observe, and note down, the following quantities, which we will denote by the symbols prefixed to them:

t' = The temperature of the air.

h' = The distance in inches and parts, as shown by the fixed scale, from zero to the junction line of the oil and water, in the glass tube, the area of which is a. Also let

p' = The pressure of the atmosphere at the second station; and

f' = The tension of watery vapour, saturated, at temperature t'

On referring to [105], it will be seen that the tension of the mixture of air and watery vapour, at the second station, after opening the cock l, will be

$$p' + (h' - h)\left(\frac{S - s + \frac{a}{A}(S + s)}{S}\right)$$

the tension of the confined air, at the second station, will be; see (33),

$$p' + (h' - h)\left(\frac{S - s + \frac{a}{A}(S + s)}{S}\right) - f'$$

The pressure of the air and watery vapour, at the first station, is expressed by p; the tension of the confined air only, at the same point, being p — f. Now, since the volume assumed by the enclosed air, exclusive of the vapour mixed with it, which may vary; is directly proportional to the sum of the temperature, and the constant number 459; and at the same time, inversely to the tension or pressure; we have,

$$\text{As } \frac{459 + t^{\circ}}{p - f} : \frac{459 + t'}{p' + (h' - h)\left(\frac{S - s + \frac{a}{A}(S + s)}{S}\right) - f'} :: b : b + (h' - h)a$$

from whence comes the equation,

$$p' = \frac{(459 + t')(p - f)\,b}{(459 + t^{\circ})\{b + (h' - h)a\}} - (h' - h)\left(\frac{S - s + \frac{a}{A}(S + s)}{S}\right) + f' \quad ..[108]$$

by means of which, after taking the observations which have been stated, the pressure of the atmosphere at the second point of observation, can be calculated, in such a manner, as, that any error which may have arisen in determining the atmospheric pressure, by a barometer or sympiesometer, at the first station, will be sensibly the same in amount here, so that by taking the difference

$$p - p'$$

when p' is determined as above, we shall obtain, to great nicety, the excess of pressure at one station, over that at the other.

It will, of course, be desirable to make the observations at the two points as quickly after each other as may be, and even to repeat them more than once, so that no error may arise from altered conditions of atmospheric pressure, or in the loss by resistance, owing to a change in the quantity of air circulating at the times of observation.

Having thus determined the difference of pressure, between the two points in the air-way, and observed the quantity of air circulating at the times of observing such difference, it remains to calculate the effects of the gravitation of the air in the ascending and descending parts of the intermediate air-way; these, being separated from the total, will, if all has been correct, always leave an excess of pressure, as existing at that point of observation from which the air commences to traverse the air-way under notice, over that existing at the opposite end, by which the

air leaves the air-way under notice; and this excess is the actual expenditure of pressure on the other resistances of the intervening air-way, (excluding the effects of gravitation only), when the observed quantity of air is circulating through it; and by [57] or [60], we can therefrom determine the specific resistance of such intermediate air-way; only using the difference of pressure in lieu of $D_o - U_o$, or $d \left\{ \frac{T - t}{459 + t} \right\}$

When h is greater than h', owing to the air contracting at the second station, the value of (h' — h) will, of course, be negative; but the formulæ given will apply with the same accuracy, as in the opposite case.

(79.) As was intimated, the great inconvenience attending the use of such an instrument, would be, that the expansion of the confined air, by heat, would cause an immense change in the volume of air, and so require the scale to be very long; or, on the other hand, the total quantity of confined air would require to be so small, as to render the instrument little, or perhaps no more sensitive than the ordinary water-gauge. At ordinary temperatures 1° of Fahrenheit would, if added to the temperature of the confined air, expand its volume, nearly as much as an inch of water-pressure would do, by being removed.

To remedy the evil complained of, the instrument might, at the times of making the observations, be immersed in a tall glass vessel containing a mixture of water and melting ice, (excepting only the mouth of the tubes projecting from the sides of the metallic vessel, which might project upwards), so as to ensure the temperature of the vessel and its contents, being 32°; and although this would be rather a troublesome process, it would render any observations of temperature needless, would simplify the formulæ for finding the difference of pressure, save all reference to tables of the tension of watery vapour, and admit of the instrument being made very much more sensitive than an ordinary water-gauge; by enlarging the metallic vessel, without making the scale of the instrument very long. According to Magnus, the tension of watery vapour at 32° is ·178,62 inches of mercury; and according to Regnault it is ·181,58 inches, the density of the mercury being that due to a temperature of 60°, and adopting the average, it is equal to ·180,1 inches of such mercury, or 2·442,15 inches of water; which, in this case, will, therefore, be the value of f, and also of f', and the formula will become

$$p' = \frac{(p - 2{\cdot}44)\, b}{b + (h' - h)\, a} - (h' - h)\left(\frac{S - s + \frac{a}{A}(S + s)}{S} \right) + 2{\cdot}44 \ldots [109]$$

If, therefore, in such case, $p = 402{\cdot}44$; $b = 249{\cdot}9$; $h' = 30$ and $h = 29$; $a = \frac{1}{10}$; $S = 1000$; $s = 940$; and $A = 40$; we shall find that $p' = 402{\cdot}215{,}15$; so that a difference of actual pressure equal to ·224,85 inches of water-column, would be indicated by a movement of the junction line, over 1 inch of the scale, the instrument being 4½ times as sensitive as a water-gauge.

(80.) In order to convert any pressure per unit of surface expressed in feet of air column, into the same, when expressed in inches of water-column; or the reverse; since the weight of a cubic foot of air is expressed, [43], in lbs., by

$$w = \frac{1{\cdot}3244\ f}{459 + t}$$

and the weight of a cubic foot of water at 62°, and 30 inches barometrical pressure, is 62·32102 lbs. avoirdupoise; and since the heights required, for the production of equal pressures per unit of surface, must be inversely as the densities of the fluids composing them; if by I, we represent the height of a column of water in inches, and by H the height of a column of air in feet, capable of producing the same pressure, we have,

$$\text{As } 62{\cdot}32102 : \frac{1{\cdot}3244\ f}{459 + t} :: H : \frac{I}{12}$$

and hence,

$$I = \frac{{\cdot}255\ f\ H}{459 + t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [110]$$

and,

$$H = \frac{3{\cdot}92133\ I\ (459 + t)}{f} \quad \ldots\ldots\ldots\ldots\ldots\ldots [111]$$

by which these conversions can be effected; they may occur in calculations regarding ventilation.

(81.) In order to convert any pressure per unit of surface, expressed in inches of mercury, into the same pressure, expressed in inches of water-column, we obtain the rule by taking into consideration, that at 32° the specific gravity of mercury is 13,598, that of water being 1,000; and that mercury has been found to expand 1-9,958th part of its volume at zero of Fahrenheit's scale, for each degree of heat imparted to it, so that its density at any temperature t, will be found by the expression,

$$\frac{13{,}598 \times (9{,}958 + 32)}{9{,}958 + t}$$

to that of water, taken as 1,000. And since the heights required, in columns of different densities, to produce equal pressures, are inversely proportional to such densities; we have,

$$1000 : \frac{13{,}598 \times (9{,}958 + 32)}{9{,}958 + t} :: B : I$$

where B is the inches of mercury, and I the inches of water; giving,

$$I = \frac{135{,}844\ B}{9{,}958 + t} \quad \ldots\ldots\ldots\ldots [112]$$

and,

$$B = \frac{(9{,}958 + t)\ I}{135{,}844} \quad \ldots\ldots\ldots\ldots [113]$$

By making the two values of I in [110] and [112], respectively, equal to each other, a formula could be obtained for converting an air, or a mercurial column, into a column of the other, of equal pressure; the former expressed in feet, and the latter in inches—these formulæ, however, are based on the assumption of the air-column being homogeneous throughout its extent, and the same as at the point of observation; this being what is wanted for application in most of the formulæ given in this memoir.

(82.) It may not, perhaps, be out of place to notice here, that, if by v we denote the velocity of a wind, in feet per minute; and by I, the inches of water-column, supported by the impulse of the wind; then, by Hutton's experiments,

$$I = \frac{v^2}{9{,}921{,}600} \quad \ldots\ldots\ldots\ldots [114]$$

and

$$v = 3150 \sqrt{I} \quad \ldots\ldots\ldots\ldots [115]$$

Other writers give rules, based upon different experiments from those of Hutton, which give greater forces, for equal velocities, than the above formulæ, which I have constructed to agree with Hutton's experiments.

Indeed, Borda's experiments give pressures about one-third greater than those made by Hutton, for equal velocities.

Since the weight in lbs. of a cubic foot of air is expressed by

$$w = \frac{1{\cdot}3244\ f}{459 + t}$$

the pressure per foot arising from a column of air, H feet high, will be,

$$p = \frac{1{\cdot}3244\ f\ H}{459 + t}$$

where p is the pressure in lbs. per foot; and we will find the height of air column, required to produce any given pressure, by,

$$H = \frac{(459 + t)\ p}{1{\cdot}3244\ f}$$

(83.) Experiments have been made by Dalton, and also by Ure, in England; and by Magnus, and also by Regnault, on the Continent, to determine the tension of aqueous vapour at different temperatures; and as the results of Magnus agree very closely with those of Regnault, I have deemed it worth while reducing their results, from tables where the temperatures are given in degrees of the Centigrade thermometer, and the corresponding tensions in millimetres of mercury, of the density due to 0° Centigrade; into temperatures expressed in degrees of Fahrenheit's thermometer, and corresponding tensions expressed in inches of mercury of the density due to a temperature of 60° of Fahrenheit's thermometer; and I have also given the tensions, as contained in the tables by Dalton and Ure.

In using the table for the preceding calculations it will, in general, be desirable to adopt and adhere to the results of one particular authority, so that the discrepancies may effect the results as little as may be.

TABLE 10.

Table of the Tension or Elastic Force of Aqueous Vapour at different Temperatures, expressed in Inches of Mercury.

Temperature.	TENSION OF VAPOUR.			
	Magnus.	Regnault.	Dalton.	Ure.
−25·6	....	0·012		
23·8	....	0·013		
22·0	....	0·014		
20·2	....	0·016		
18·4	....	0·017		
16·6	....	0·018		
14·8	....	0·020		
13·0	....	0·022		
11·2	....	0·024		
9·4	....	0·026		
7·6	....	0·028		
5·8	....	0·031		
4·0	0·036	0·033		
2·2	0·039	0·036		
0·4	0·043	0·039		
+1·4	0·047	0·043		
3·2	0·051	0·047		
5·0	0·055	0·051		
6·8	0·060	0·055		
8·6	0·065	0·060		
10·4	0·071	0·065		
12·2	0·077	0·071		
14·0	0·083	0·078		
15·8	0·090	0·085		
17·6	0·098	0·092		
19·4	0·105	0·100		
21·2	0·114	0·109		
23·0	0·123	0·119		
24·8	0·133	0·129		
26·6	0·143	0·140		
28·4	0·154	0·153		
30·2	0·166	0·167		
32·0	0·179	0·182	0·200	0·200
33·0	....	....	0·207	
33·8	0·192	0·195		
34·0	....	....	0·214	
35·0	....	....	0·221	
35·6	0·207	0·209		
36·0	....	....	0·229	
37·0	....	....	0·237	
37·4	0·222	0 225		
38	....	....	0·245	
39	....	....	0·254	
39·2	0·238	0·240		
40	....	....	0·263	0 260
41·0	0·255	0·257	0·273	
42	....	....	0·283	
42·8	0·274	0·276		
43·0	....	....	0·294	
44·0	....	....	0·305	
44·6	0·294	0·296		
45	....	....	0·316	
46	....	....	0·328	

Temperature.	TENSION OF VAPOUR.			
	Magnus.	Regnault.	Dalton.	Ure.
46·4	0 314	0·317		
47	....	....	0·339	
48	....	....	0·351	
48·2	0·337	0·339		
49	....	....	0·363	
50	0·360	0·362	0·375	0·360
51	....	....	0·388	
51·8	0·385	0·387		
52	....	....	0 401	
53	....	....	0·415	
53·6	0·411	0·413		
54	....	....	0·429	
55	....	....	0·443	0·416
55·4	0·439	0·441		
56	....	....	0·458	
57	....	....	0·474	
57·2	0·469	0·470		
58	....	....	0·490	
59	0·500	0·501	0·507	
60	....	....	0·524	0·516
60·8	0·536	0·534		
61	....	....	0·542	
62	....	....	0 560	
62·6	0·569	0·569		
63	....	....	0·578	
64	....	....	0·597	
64·4	0·606	0·606		
65	....	....	0·616	0·630
66	....	....	0·635	
66·2	0·645	0·645		
67	....	....	0·655	
68	0·687	0·687	0·676	
69	....	....	0·698	
69·8	0·731	0·730		
70	....	....	0·721	0·726
71	....	....	0·745	
71·6	0·777	0·776		
72	....	....	0·770	
73	....	....	0·796	
73·4	0·826	0·825		
74	....	....	0·823	
75	....	....	0·851	0·860
75·2	0·877	0·876		
76	....	....	0 880	
77	0·931	0·930	0·910	
78	....	....	0·940	
78·8	1·012	0·987		
79	....	....	0·971	
80	....	....	1·000	1·010
80·6	1·048	1·046		
81	....	....	1·04	
82	....	....	1·07	
82·4	1·111	1·109		
83	....	....	1·10	
84	....	....	1·14	
84·2	1·178	1·176		
85	....	....	1·17	1·170
86	1·248	1·246	1·21	
87	....	....	1·24	

Temperature.	TENSION OF VAPOUR.			
	Magnus.	Regnault.	Dalton.	Ure.
87·8	1·321	1·319		
88	....	....	1·28	
89	....	....	1·32	
89·6	1·398	1·396		
90	....	....	1·36	1·360
91	....	....	1·40	
91·4	1·479	1·477		
92	....	....	1·44	
93	....	....	1·48	
93·2	1·565	1·562		
94	....	....	1·53	
95	1·654	1·651	1·58	1·640
96	....	....	1·63	
96·8	1·748	1·745		
97	....	....	1·68	
98	....	....	1·74	
98·6	1·846	1·843		
99	....	....	1·80	
100	....	....	1·86	1·860
100·4	1·949	1·946		
101	....	....	1·92	
102	....	....	1·98	
102·2	2·057	2·055		
103	....	....	2·04	
104	2·170	2·168	2·11	
105	....	....	2·18	2·100
105·8	2·289	2·286		
106	....	....	2·25	
107	....	....	2·32	
107·6	2·413	2·410		
108	....	....	2·39	
109	....	....	2·46	
109·4	2·542	2·540		
110	....	....	2·53	2·456
111	....	....	2·60	
111·2	2·678	2·676		
112	....	....	2·68	
113	2·820	2·819	2·76	
114	....	....	2·84	
114·8	2·968	2·967		
115	....	....	2·92	2·820
116	....	....	3·00	
116·6	3·123	3·123		
117	....	....	3·08	
118	....	....	3·16	
118·4	3·285	3·285		
119	....	....	3·25	
120	....	....	3·33	3·300
120·2	3·454	3·455		
121	....	....	3·42	
122	3·631	3·631	3·50	
123	....	....	3·59	
123·8	3·815	3·816		
124	....	....	3·69	
125	....	....	3·79	3·830
125·6	4·007	4·009		
126	....	....	3·89	
127	....	....	4·00	
127·4	4·207	4·210		

Temperature.	TENSION OF VAPOUR.			
	Magnus.	Regnault.	Dalton.	Ure.
128	....	....	4·11	
129	....	....	4·22	
129·2	4·417	4·420		
130	....	....	4·34	4·366
131	4·634	4·638	4·47	
132	....	....	4·60	
132·8	4·861	4·866		
133	....	....	4·73	
134	....	....	4·86	
134·6	5·097	5·064		
135	....	....	5·00	5·070
136	....	....	5·14	
136·4	5·340	5·350		
137	....	....	5·29	
138	....	....	5·44	
138·2	5·600	5·607		
139	....	....	5·59	
140	5·866	5·875	5·74	5·770
141	....	....	5·90	
141·8	6·143	6·153		
142	....	....	6·05	
143	....	....	6·21	
143·6	6.432	6·442		
144	....	....	6·37	
145	....	....	6·53	6·600
145·4	6·732	6·743		
146	....	....	6·70	
147	....	....	6·87	
147·2	7·043	7·055		
148	....	....	7·05	
149	7·367	7·881	7·23	
150	....	....	7·42	7·530
150·8	7·704	7·718		
151	....	....	7·61	
152	....	....	7·81	
152·6	8·053	8·069		
153	....	....	8·01	
154	....	....	8·20	
154·4	8·416	8·433		
155	....	....	8·40	8·500
156	....	....	8·60	
156·2	8·793	8·811		
157	....	....	8·81	
158	9·183	9·203	9·02	
159	....	....	9·24	
159·8	9·589	9·608		
160	....	....	9·46	9·600
161	....	....	9·68	
161·6	10·010	10·031		
162	....	....	9·91	
163	....	....	10·15	
163·4	10·446	10·468		
164	....	....	10·41	
165	....	....	10·68	10·800
165·2	10·898	10·921		
166	....	....	10·96	
167	11·366	11·391	11·25	
168	....	....	11·54	
168.8	11·852	11·877		
169	....	....	11·83	
170	....	....	12·13	12·050

Temperature.	TENSION OF VAPOUR.			
	Magnus.	Regnault.	Dalton.	Ure.
170·6	12·355	12·381		
171	....	....	12·43	
172	....	....	12·73	
172·4	12·876	12·903		
173	....	....	13·02	
174	....	....	13·32	
174·2	13·415	13·443		
175	....	....	13·62	13·550
176	13·973	14·001	13·92	
177	....	....	14·22	
177·8	14·551	14·580		
178	....	....	14·52	
179	....	....	14·83	
179·6	15·149	15·177		
180	....	....	15·15	15·160
181	....	....	15·50	
181·4	15·767	15·796		
182	....	....	15·86	
183	....	....	16·23	
183 2	16·406	16·436		
184	....	....	16 61	
185	17·067	17·097	17·00	16·900
186	....	....	17·40	
186·8	17·751	17·779		
187	....	....	17·80	
188	....	....	18·20	
188·6	18·457	18·486		
189	....	....	18·60	
190	....	....	19·00	19·000
190·4	19·187	19·215		
191	....	....	19·42	
192	....	....	19·86	
192·2	19·941	19·968		
193	....	....	20·32	
194	20·719	20·745	20·77	
195	....	....	21·22	21·100
195·8	21·521	21·548		
196	....	....	21·68	
197	....	....	22·13	
197 6	22·352	22·376		
198	....	....	22·69	
199	....	....	23·16	
199·4	23·212	23 231		
200	....	....	23·64	23 600
201	....	....	24·12	
201·2	24·092	24·113		
202	....	....	24 61	
203	25·003	25·022	25·10	
204	....	....	25·61	
204·8	25·944	25·960		
205	....	....	26·13	25 900
206	....	....	26·66	
206·6	26·914	26·927		
207	....	....	27·20	
208	....	....	27·74	
208·4	27·913	27·924		
209	....	....	28 29	
210	....	....	28·84	28 880
210·2	28·944	28·952		
211	....	....	29·41	
212	30·006	30·006	30·00	30 00

CHAPTER VIII.

Example of the Application of the Specific Resistances of the Air-ways of a Mine, for determining the Effects, on the Ventilation of a Mine, which would be produced by a "Change of Air."

Having shewn how the specific resistances of an air-way, or any portion of an air-way, may be found by calculation, providing we know the exact difference of the barometrical pressures, existing at its two extremities, together with the ascents and descents traversed by the air in passing from one point to the other, and the temperature of the air in each part; it may, at least, serve as a general illustration of many of the preceding parts of this memoir, to proceed to shew, by an imaginary case, assumed as an example, how such specific resistances, when found for all parts of the air-ways of a mine, may be made use of to determine the particular effects which would be produced on the ventilation of each part of such mine, by effecting any proposed or contemplated alteration in the arrangements for ventilating it; in other words, to shew how a knowledge of such resistances would enable us to determine the exact quantity of air, which would circulate in each of the new "splits," under any given or assumed general ventilating pressure; after making any proposed or contemplated "change of air." In offering the following example, it is not presumed that the very troublesome mode which has been suggested for finding the exact amount of very minute differences of pressure, existing at different points in an air-way, situated at a distance from each other, is such as to be likely to be often resorted to; yet it is hoped that such an example, by calling attention to the use which could be made of a knowledge of such differences of pressure, may at least have the effect of leading to an attempt being made to devise some less objectionable method than that alluded to, for determining with sufficient accuracy, the amount of any such differences of pressure; as the attainment of this object, certainly appears, in the abstract, to be quite possible.

Supposing the general features of the ventilation of a coal mine to be shewn by the figure in Plate 2.

And, for the sake of simplifying the case, let it be presumed that the entire extent of the air-ways are situated in the same horizontal plane, so that the pressures and the ventilation are not affected by any constant forces, arising from the gravitation of the air in ascending or descending parts of the air-ways.

In the first place, let us suppose the air to be divided into no more than two distinct currents, represented in Plate 2 by the arrows; the currents separating at the bottom of the downcast shaft *a*; one current passing to the right through b, c, d, *over* an air-tight crossing at e, through f, r, g, over the furnace at x, and up the upcast shaft at z; the other current leaving the bottom of the downcast shaft at a, and going to the left, through *under* the air-tight crossing at e, thence through h, i, k, l, m, n, and joining the first current at g; and, in connexion with it, going to, and over the furnace at x, and up the upcast shaft at z.

Let it be presumed that we wish to know what would be the effect on each part of the ventilation of the mine, if the arrangements were so altered, as to divide the air in the following manner; on the assumption of the total ventilating *pressure* being maintained at the same amount, after, as before the change—

1st. Let one current, which we shall call No. 1, pass from the bottom of the downcast shaft, as in Plate 3, through b, c, p, to and over a new crossing to be placed at q, (the doors on each side of it being removed,) and thence to x, over the furnace and up the upcast shaft.

2nd. Another current No. 2, being a split from No. 1, which it separates from at b, goes thence through m, n, g, and so to x, and up the upcast shaft; the stopping between b and m being removed.

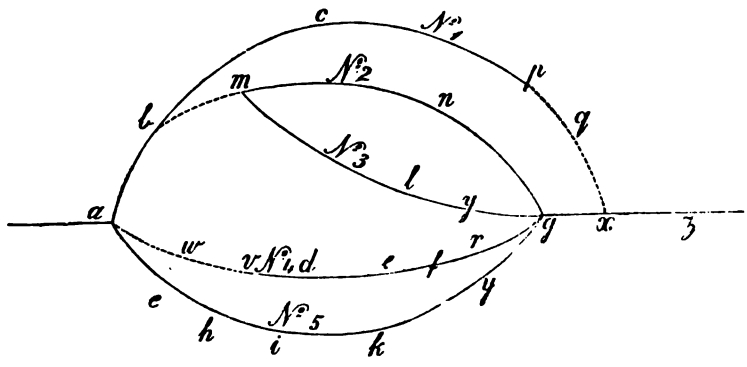
3rd. Another current, No. 3, being a split from No. 2, leaving it at m, passing through l, y, g, and so to the furnace at x, and up the upcast shaft—the stopping at y being removed.

4th. Another current, No. 4, dividing from the other air at the bottom of the downcast shaft, and passing through w, v, d, over the crossing at e, to f, r, g, and x, and thence up the upcast shaft—this requiring the removal of the doors near w, and also the placing of a door or stopping at v.

We will also presume the regulator at r to be removed on changing the air.

5th. Another portion of air No. 5, separating from the general body of air at the bottom of the downcast shaft at a, and passing under the crossing at e, and thence through h, i, k, y, g and x, and up the upcast shaft at z—a stopping or door near y being taken away on making the change.

The following diagram will serve to exhibit the general connexion existing between the currents after the change has been effected:



The dotted lines represent galleries or air-ways not traversed by any current before the change is effected, but which will be ventilated after it is effected—while from p to v, on the contrary, will cease to be ventilated after the change is effected, although previously ventilated—and hence the specific resistances of these parts will require to be determined, by taking the dimensions of the air-way, and calculating by the formulæ which have been given for the purpose, in another place;—so far, at least, as regards the parts where no air is circulated before the change; inasmuch as where there is no current there cannot be any loss of pressure from resistances.

Since we have presumed the workings of the mine to be level, the specific resistance of the ventilated passages will be found by dividing the loss of pressure, (expressed in feet of air column, of some density, assumed as a standard), by the square of the number of cubic feet of air in circulation per minute; only excepting in the shafts, and it is presumed that enough has been said to render clear the mode of proceeding to obtain their resistances; it only involving, in addition to the rules for horizontal passages, the necessary allowance for the weight of the air in them, in certain instances.

A consideration of the diagram just presented, together with the figure

in Plate 3; where the arrows denote the route taken by the air after the change, will shew where observations should be made.

Let it be presumed that we are using an oil and pressure gauge, of such a size and character that it is 5 times as sensitive as a water gauge; and that the pressures due, represented in feet of air column, of a density such as to cause it to weigh ·078 lbs. per cubic foot—this being the weight due to dry air at 51° under a pressure of 30·03637 inches of mercury:—the total ventilating pressure being equal to 100 feet of such air. Then will the following table exhibit the results of the necessary observations, which must be taken at the points indicated by the letters.

In the 1st Split 8,000 feet per minute.

Points of Observation, as on Plan. 1st Point.	2nd Point.	Movement of junction line of oil and water in the gauge.	Pressures in column of air $\frac{1}{800}$ of the weight of water.	Cubic feet of air in circulation per minute.	Specific resistance of the intervening air-way.	
		Inches.	$\frac{800\ C}{5 \times 12}$	Observed quantities.	$\frac{D}{E^2}$	
A	B	C	D	E	F	
Downcast Shaft.		0·375	5	20,649	(7) 11,725	
a	b	0·15	2	8,000	(7) 31,250	
b	p	1·05	14	8,000	(6) 218,750	
p	r	3·075	41	8,000	(6) 640,625	This is the pressure due to the resistance offered by the regulator.
r	g	1·5	20	8,000	(6) 312,500	
g	x	0·225	3	20,649	(8) 7,050	
Upcast Shaft, including the pressure due to the final velocity.....		....	15	20,649	(7) 35,175	
			100			

In the 2nd Split of 12,649 feet per minute.

Downcast shaft.		0·375	5	20,649	(7) 11,725	
a	y	2·25	30	12,649	(6) 187,500	
y	m	1·875	25	12,649	(6) 156,250	
m	g	1·65	22	12,649	(6) 137,500	
g	x	·225	3	20,649	(8) 7,050	
Upcast Shaft, including the pressure due to the final velocity.....		....	15	20,649	(7) 35,175	
			100			

It will be seen from the tables that we have supposed 8,000 feet of

air per minute, to have circulated in the 1st Split, and 12,649 cubic feet per minute, in the 2nd Split, at the times of observation, before the "change."

In order that the table given may be understood, as well as many of the calculations which are to follow, it is necessary to explain that, having for perspicuity adopted 1 cubic foot of air per minute, as the unit whereby to determine what is here denominated the "specific resistance of an air way," the result is, that these resistances are so very minute that they would generally require the prefixing of a great number of cyphers before the digits, to express them in decimal notation; and to avoid this inconvenience, the numbers *enclosed in parentheses* indicate the number of cyphers which actually require to be, (yet which are not) prefixed to the digital parts of the numbers, in order correctly to express them.

In future calculations, it would be better to adopt a thousand cubic feet per minute as the standard, whereby to determine specific resistances, so as to reduce the number of cyphers required; in such case, bearing in mind that the results would not come out in cubic feet, but in cubes of air, 10 feet square on each side; that is to say, in *thousands* of cubic feet.

In the notation just mentioned the number (7) 11,725 = ·000,000,011,725, and the number (6) 218,750 = ·000,000,218,750, &c.

By the use of such a gauge as we have supposed in this example mine, the errors of observation would not in any case amount to more than $\frac{1}{150}$th part of the total ventilating pressure employed, even if we suppose that the error was as great as $\frac{1}{20}$th of an inch on the scale of the instrument; because $\frac{12 \times 5 \times 100}{800} = 7\frac{1}{2}$ inches of scale on the gauge would be required to indicate the total pressure of 100 feet of air column; $\frac{1}{800}$th part of the density of water; the instrument being 5 times as sensitive as a water pressure gauge; and $7\frac{1}{2} \times 20 = 150$—20th parts of an inch.

On referring to the diagram, it will be seen that we have not got, in our tabulated observations, the specific resistances of the following parts of the air-ways; owing to their being *dumb* before the change.

In No. 1 split, from p through q to x.

From b to m, uniting No. 1 with Nos. 2 and 3 splits.

From a to v in No. 4 split.

As they will form a part of the routes traversed by the air after the change, it will be necessary to know beforehand, what their specific resist-

ances really are; and this can only be ascertained by taking their dimensions, and calculating them by the rules given in an earlier page; and even to do this will require a knowledge of the coefficient of resistance, due to the nature of the materials composing the interior surfaces of such air-ways, and which it may, therefore, be worth while ascertaining, by a series of experiments on passages exposing different kinds of mineral substances to moving air, the general rules given in Chapter 5 of this memoir will enable us to determine these coefficients.

After calculating the amounts of the specific resistances of the parts just alluded to, they will have to be added to those of the remainder of the particular routes, of which they are intended to form a part, after the change of air.

From p to v, which is to become dumb or unventilated after the change of air, will also require that its specific resistance be found, either by the use of the gauge, or by measurement and calculation, and deducted from No. 4 split's specific resistance as found from observations at b and r, &c.

Let us suppose that we have so determined these resistances, and found them to be as follows:—

From p through q to x ..	=	(9) 6.
From b to m	=	(9) 2.
From a through w to v	=	(9) 2.
From p to v	=	(9) 1.
Let it further be presumed that we have calculated, by the formula given, or actually observed by the gauge, that the loss of pressure at the regulator r, is equal to a specific resistance of. See [1] and [64]..... ..	=	(6) 3123.

Then, after the change of air is effected, it follows that the specific resistances offered to the several splits of air, will be, as in the following tabular statement; on the presumption that each current is pursued from its entering the mouth of the downcast shaft, till it is discharged at that of the upcast shaft.

TABLE,

Shewing the specific resistances of each of the routes, taken by the different splits of air in the example, after effecting the change.

No. of Split.	Reference to the route of the splits, as given on the Plan.			Specific resistances.	
	Commencement.	Intermediate.	Ending.	Of the portions separately.	Of the entire route, being the sum of the portions.
1	Top.	Downcast Shaft.	Bottom.	(7) 11,725	
	a		b	(7) 31,250	
	b		p	(6) 218,750	
	p	q	x	(9) 600	
	Bottom.	Upcast Shaft.	Top.	(7) 35,175	(6) 297,500
2	Top.	Downcast Shaft.	Bottom.	(7) 11,725	
	a		b	(7) 31,250	
	b		m	(9) 200	
	m	n	g	(6) 137,500	
	g		x	(8) 7,050	
	Bottom.	Upcast Shaft.	Top.	(7) 35,175	(6) 222,900
3	Top.	Downcast Shaft.	Bottom.	(7) 11,725	
	a		b	(7) 31,250	
	b		m	(9) 200	
	m	l, y	g	(6) 156,250	
	g		x	(8) 7,050	
	Bottom.	Upcast Shaft.	Top.	(7) 35,175	(6) 241,650
4	Top.	Downcast Shaft.	Bottom.	(7) 11,725	
	a	w	y	(9) 200	
	b	(less p to v)	r	(6) 640,525	
	r	(less regulator)	g	(9) 200	
	g		x	(8) 7,050	
	Bottom.	Upcast Shaft.	Top.	(7) 35,175	(6) 694,875
5	Top.	Downcast Shaft.	Bottom.	(7) 11,725	
	a	e, h, i, k, y	g	(6) 187,500	
	g		x	(8) 7,050	
	Bottom.	Upcast Shaft.	Top.	(7) 35,175	(6) 241,450

An inspection of the diagram, shews that in order to apply the formulæ, to determine the gross resistances encountered by each of the new splits of air, both where they are alone, and in the parts of their routes where the resistance encountered is enhanced, by the union of other currents with any one under particular consideration; we must treat the 4th and 5th splits or routes as acting in aid of each other from a to g, so as to obtain the specific resistance of a single route, which would be equal to their joint effects in transmitting air; and then proceed, in a similar manner, to find the specific resistance of a single route, which would transmit, under equal pressures, the same quantity of air, as the joint quantities transmitted by Nos. 2 and 3 routes, from m to g; and afterwards determine the case for one split of air, dividing itself into two parts, one of which pursues one route and the other a different one, so

that one of them unites with a distinct split or current, and, in conjunction with it, passes some distance; where they are met by, and united to, the remaining part of the first mentioned current; and pass on to the top of the upcast shaft with it; all of which will be more readily perceived by considering the following processes of calculation, perhaps, than by any direct consideration of the diagram alone.

We perceive by [69] that

$$M = \frac{M_1 \; M_2}{M_1 + 2 \sqrt{M_1 \, M_2} + M_2}$$

where M is the specific resistance due to a passage giving the same facilities for the transmission of air as the united actions of M_1 and M_2.

If by $m_{(4,5)}$ we represent the resistance of a passage, equivalent to the united actions of routes 4 and 5, from a to g, in transmitting air; and if by m_4 we represent the specific resistance of route 4 from a to g; and by m_5 that of route 5 between the same points; then by substitution, in [69], we obtain,

$$m_{(4,5)} = \frac{m_4 \; m_5}{m_4 + 2 \sqrt{m_4 \, m_5} + m_5}.$$

Now the specific resistance m_4 is (6) 640,925

Viz:—

From a through w to v	(9)	200
From v to r = p to r less p to v	(6)	640,525
From r to g = (6) 312,500		
Less, Regulator (6) 312,300 =	(9)	200
Therefore m_4 =	(6)	640,925

The specific resistance of that part of split 5, from a to g, passing through e, h, i and k is m_5 = (6) 187,500; and hence,

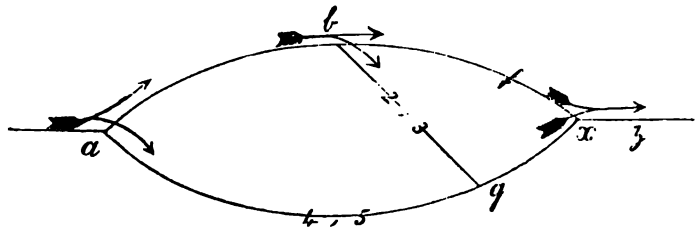
$$m_{(4,5)} = \frac{(6)\ 640{,}925 \times (6)\ 187{,}500}{(6)\ 640{,}925 + 2\sqrt{(6)\ 640{,}925 \times (6)\ 1875} + (6)\ 1875} = (7)\ 78{,}971$$

The specific resistance of routes 4 and 5, so far as regards the parts extending from a to g only, when acting in aid of each other in transmitting air, is therefore (7) 78,971 as above.

Proceeding now in a similar manner to find the joint resistance of routes 2 and 3, from m to g; that of 2 from m to g is (6) 137,500; and that of No. 3 route between the same points is (6) 156,250: the united effects reduce the resistance to,

$$\frac{(6)\ 137{,}5 \times (6)\ 156{,}25}{(6)\ 137{,}5 + 2 \times \sqrt{(6)\ 137{,}5 \times (6)\ 156{,}25} + (6)\ 156{,}25} = (7)\ 36{,}607$$

These operations virtually reduce our directing diagram to the form of,



Referring to the above figure the resistances are:

From a to g *via* 4, 5, ... = (7) 78,971
From a to b ..... = (7) 31,250
From b to g, viz., b to m..... = (9) 200
and m to g *via* 2, 3,.. = (7) 36,607 = (7) 36,807
From b to x *via* c l p and q in No. 1 Route
is, from b to p..... = (6) 218,750
and from p through q to x.. = (9) 600 =(6) 219,350
From g to x..... =(8) 7,050

We now require to determine the proportions in which air would divide itself over the series of routes offered to it, disposed as in the above diagram, with respect to each other, and having the specific resistances given above—where, it will be seen, a branch or split from one current, after leaving its parent current at b, joins another current at g, and in union with it traverses some distance, till at x they are joined by the parent current itself, and thence proceed, in a united state, to the shaft at z.

In such a case, when the entire quantity of air, or the sum of all the currents is 1 cubic foot per minute, (the unit which has been adopted as a standard for finding our specific resistances;) if we represent by c the quantity in the route which the branch current joins; and if we represent the quantity of the branch current itself by b, then will (1 — c) be the quantity in the parent current, before the branch current separates from it; and (1 — c — b) will be the quantity in the parent current after the branch current has left it; while the current of c will be increased to (c + b) after being joined by the branch current.

And if m represent the specific resistance of an air-way, equivalent in transmitting power to the joint action of all the air-ways; that is to say,

if m = the pressure, in feet of air-column, capable of transmitting one cubic foot of air per minute, through the air-ways; and if, in addition thereto

The specific resistance in the part traversed by $1 - c$ is m_1

Do.	Do.	c is m_2
Do.	Do.	b is m_3
Do.	Do.	$(1 - c - b)$ is m_4
Do.	Do.	$(c + b)$ is m_5

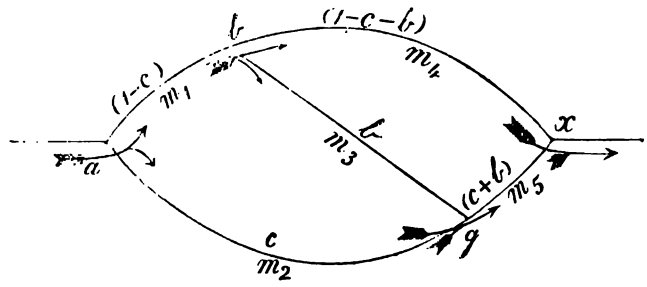
Then, since the currents will necessarily so divide themselves over the three routes leading from a to x, that the loss of pressure, owing to the resistances encountered in each route, shall be exactly the same in the two currents uniting at x; and also in those uniting at g; reckoning the loss from the points where they respectively separated from each other. And since the square of the quantity of air in each part, multiplied into the specific resistance of that part, is equal to the pressure expended on the resistances, we obtain the following series of equations:

$$m = (1 - c)^2 m_1 + b^2 m_3 + (c + b)^2 m_5 \quad \ldots\ldots\ldots\ldots \quad [116]$$

$$m = c^2 m_2 + (c + b)^2 m_5 \quad \ldots\ldots\ldots\ldots \quad [117]$$

$$m = (1 - c)^2 m_1 + (1 - c - b)^2 m_4 \quad \ldots\ldots\ldots\ldots \quad [118]$$

The origin of which may be better seen, perhaps, by reference to the following sketch, where the quantities and resistances are marked on the routes to which they apply; the compression of the air of the currents, at the points where they separate or unite, necessarily being the same.



In the above equations $m_1 = (7)\ 31{,}250$, $m_2 = (7)\ 78{,}971$, $m_3 = (7)\ 36{,}807$, $m_4 = (6)\ 219{,}350$, $m_5 = (6)\ 705$, and it is required to find the values of the quantities of air represented by c and b together with that of m.

Deducting [117] from [116] we obtain

$$(1 - c)^2 m_1 + b^2 m_3 - c^2 m_2 = 0 \quad \ldots\ldots\ldots\ldots \quad [119]$$

and by deducting [118] from [116] we obtain

$$b^2 m_3 + (c + b)^2 m_5 - (1 - c - b)^2 m_4 = o \quad \ldots\ldots \quad [120]$$

and from [119] there comes

$$b^2 = \frac{c^2 m_2 - (1 - c)^2 m_1}{m_3} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [121]$$

And since it would require the solution of a biquadratic equation, to find the values of c and b from the above equations, it will perhaps be best to ascertain their values by approximation, or trial and error, according to the following *Rule.*

First, suppose or assume any value for c less than unity, because c is but a part of the whole air, which has been taken at unity or one cubic foot per minute; and substitute the value so assumed for c, in [121], and then, by that equation, proceed to find the corresponding imaginary values of b^2 and b; and substitute their values so found, in [120], together with the assumed value of c; and then, if the assumed values are correct, the positive and negative parts of the equation [120] will be equal to each other, as is indicated by the terms of the equation; if the positive terms exceed the negative terms in value, the error will be the excess in question, and be called a + error; if, on the other hand, the sum of the negative terms is greater than the sum of the positive terms, the excess will be called a — error; when the error is a plus error there must be assumed a new value of c, less than the first assumed value; and if on the other hand the error is a minus one, we must assume a new value of c, greater than the first assumed value; and proceed as with the first assumed value of c, by substituting it in [121], and finding the corresponding values of b^2 and b; also as before; substitute these new values of c, b^2 and b in [120], and again find the error or difference between the positive and negative parts of the resulting equation; marking the error + when the positive parts exceed the negative ones; and marking it — when the negative parts exceed the positive parts, in value.

Then multiply each assumed value of c, by the error arising from the use of the *other* assumed value of c.

After having proceeded thus far, the mode of operating will depend upon the kind of signs with which the errors are affected.

1st. If the errors be of the same affection, that is if they have like signs, so as to be both +, or both —, then subtract the one product from the other, and also the one error from the other, and divide the former of these two remainders, by the latter; and the quotient will be an approximation to the value of c.

2nd. If, however, the errors be unlike, in their signs, the one being

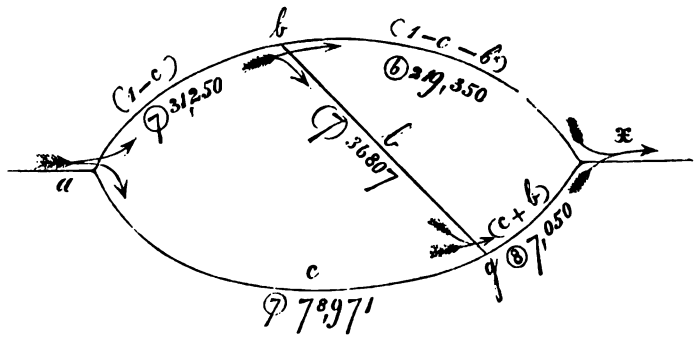
positive, and the other negative, then add the two products together, and also add the two errors together; and divide the former sum by the latter, and the quotient will be an approximate value of c.

The first approximation to the value of c, so found, may now be made use of, by finding the error to which it gives rise, and using it, in conjunction with a new assumed value of c, and its corresponding error, to approximate nearer to the true value of c; or two new values of c, one a little greater, and the other a little less than the first approximate value of c may be made use of in a precisely similar manner to the two original assumed values of c, to arrive at a nearer approximation to its true value; and these processes may be repeated until we have determined the true value of c, to any required degree of nicety.

Now we have, in the example in hand, taken, in reference to the case just investigated:

m_1 or a to b ..... = ·000,000,031,250
m_2 or a to g *via* 4, 5, ... = ·000,000,078,971
m_3 or b to g *via* m in 2, 3, ... = ·000,000,036,807
m_4 or b to x *via* c, l, p, and q, in No. 1 = ·000,000,219,350
m_5 or g to x ..... = ·000,000,007,050

which may be illustrated by the following diagram—



Let us, in proceeding to find the values of c and b, first assume c = ·4 and consequently (1 — c) = ·6, and by [121],

$$b^2 = \frac{\cdot 16 \times (7)\,78{,}971 - \cdot 36 \times (7)\,31250}{(7)\,36807} = \cdot 037629$$

and,

$$b = \sqrt{\cdot 037629} = \cdot 19398$$

and therefore, by [120],

$\cdot 037620 \times (7)\ 36807 + \cdot 59398^2 \times (8)\ 705 - 40602^2 \times (6)\ 219{,}35 =$
$- (7)\ 32{,}2877$

which is the negative error arising from assuming ·4 as the value of c.

Now let ·437 be assumed as a new value of c, and then $(1 - c) = \cdot 563$; and by [121],

$$b^2 = \frac{\cdot 437^2 \times (7)\ 78{,}971 - \cdot 563^2 \times (7)\ 31250}{(7)\ 36{,}807} = \cdot 14062$$

and consequently

$$b = \sqrt{\cdot 14062} = \cdot 37499$$

and by [120]

$\cdot 14062 \times (7)\ 36807 + \cdot 81199^2 \times (8)\ 705 - \cdot 18801^2 \times (6)\ 219{,}35 = (8)\ 20705$

which is the *plus* error corresponding to ·437 as an assumed value of c; and by the Rule given

SUPPOSITIONS.		ERRORS.		PRODUCTS.
·4	—	(7) 32,287,7	=	(7) 14,109,72
·437 ×	+	(8) 2,070,5	=	(9) 828,20
sums		(7) 34,358,2		(7) 14,937,92

and

$$\frac{(7)\ 14{,}937{,}92}{(7)\ 34{,}358{,}20} = \cdot 43477,$$ which is the first approximation towards the value of c.

To proceed, let this approximate value of c be adopted as a new assumed value of c, giving $c = \cdot 43477$; and $(1 - c) = \cdot 56523$; and

$$b^2 = \frac{\cdot 43477^2 \times (7)\ 78971 - \cdot 56523^2 \times (7)\ 31250}{(7)\ 36807} = \cdot 13430$$

and consequently,

$$b = \sqrt{\cdot 13430} = \cdot 36647$$

and hence, by [120],

$\cdot 13430 \times (7)\ 36807 + \cdot 80124^2 \times (8)\ 705 - \cdot 19876^2 \times (6)\ 21935 = (9)\ 8036$

so that this new supposition of c being = ·43477 gives a *plus* error of (9) 8036: and if we further approximate to the true value of c, by this and the preceding supposition; where the value of c was taken at ·437, and the result was a *plus* error of (8) 20705; we obtain,

·437 ×		(8) 20705	=	(9) 9001912
·43477 ×		(9) 8036	=	(9) 3511732
Differences		(8) 12669	=	(9) 5490180

and

$$\frac{(9)\ 549{,}018}{(8)\ 126{,}690} = \cdot 43335$$ which is the second approximate value

of c; and as this is very close upon the actual value of c (as may be seen by substituting it in [116], [117] and [118]), we shall adopt it, and hence,

$$c = \cdot 43335\,;\ (1 - c) = \cdot 56665\,;\ \text{and, by [119],}$$

$$b^2 = \frac{\cdot 43335^2 \times (7)\ 78971 - \cdot 56665^2 \times (7)\ 31250}{(7)\ 36807} = \cdot 1303$$

and,

$$b = \sqrt{\cdot 1303} = \cdot 36097$$

and consequently,

$$(c + b) = \cdot 79432;\ \text{and } (1 - c - b) = \cdot 20568$$

and by substitution in [116], [117], and [118],

$$m = \cdot 5665^2 \times (7)\,31250 + \cdot 36097^2 \times (7)\,36807 + 79432^2 \times (8)\,705 = (7)\,192782$$
$$m = \cdot 43335^2 \times (7)\ 78971 + \cdot 79432^2 \times (8)\ 705 \ldots\ldots\ldots\ldots = (7)\,192782$$
$$m = \cdot 56665^2 \times (7)\ 31250 + \cdot 20568^2 \times (6)\ 219350 \ldots\ldots\ldots\ldots = (7)\,193134$$

the average of which values of m $= (7)\,192899$

The value of m, (representing the total pressure required to overcome the resistance encountered by the air in the whole of the passages or routes leading from a to x, when one cubic foot per minute is the total quantity transmitted by all the routes acting in aid of each other), it will be seen, differs but little from the average, in any of the equations, each of which embrace a passage not included in the others; this slight discrepancy arises from our not having approximated more closely to the actual value of c; we may, however, safely adopt and consider the general "drag" or specific resistance, as being

$$m = (7)\ 1929$$

and by adding to this, the specific resistances of the downcast shaft, furnace, furnace drift, and upcast shaft; which are traversed by the entire body of air in the mine, and which together amount to (7) 469, we obtain the entire drag on specific resistance of the mine = (7) 6619; which is, in fact, the feet of air-column required to generate the necessary pressure, for transmitting one cubic foot of air per minute through such a mine.

If we assume that after the change of air, the same amount of ventilating pressure is employed, as was supposed to exist before the change was made, which was 100 feet of air-column; then, since $Q = \sqrt{\frac{P}{m}}$, where no constant forces of different amounts operate to affect the ventilation through the air gravitating in ascending or descending parts of the routes, beyond what is embraced by P, and acts in common, and equally

on each of the different routes, we have the total quantity of air circulating per minute, in the mine, after the change,

$$Q = \sqrt{\frac{100}{(7)\ 6619}} = 38{,}869 \text{ cubic feet.}$$

The quantity circulating before the change, under the same ventilating pressure of 100 feet of air-column, was only 20,649 cubic feet per minute; shewing that the change would, if the same pressure were employed, cause an increase in the general ventilation of more than 88 per cent., on the original quantity in circulation, before it was effected.

In practice, however, it might be important to determine the quantities which would circulate in each individual route after the change should be made; and this is done as follows, for the case in hand. The quantity in each route will be proportional to the entire quantity circulating in the mine, when the gravitation of the air in the ascending and descending parts of the air-ways does not affect the results, and hence,

As 1 : Q :: (1 — c) : Q (1 — c), or
As 1 : 38,869 :: ·56665 : 22,025 cubic feet from a to b;
and As 1 : 38869 :: ·43335 : 16,844 do. from a to g;

from which it will be seen, that we have only to multiply the quantity which is due to any route (when one cubic foot per minute is supposed to be the total quantity of air divided amongst the whole of the routes or splits), by the total quantity in circulation at any time, to obtain the quantity due to that particular route; so that,

(1 — c) Q = ·56665 × 38869 = 22,025 cubic feet from a to b
c Q = ·43335 × 38869 = 16,844 do., from a to g in 4, 5.
38,869 do., total.

And in like manner,

(1 — c — b) Q = ·20568 × 38,869 = 7,995 cubic feet, from b to x *via* 1.
(c + b) Q = ·79432 × 38,869 = 30,874 do. from g to x.
38,869 do. total.

And

b Q = ·36097 × 38,869 = 14,030 cubic feet, from b to m and in 2, 3.

But the quantity 22,025 cubic feet per minute, passing from a to b, will be distributed over Nos. 1, 2, and 3 routes; and since 7,995 has been found as due to No. 1, the remainder 14,030, (found directly as above), will be divided between routes, Nos. 2 and 3: and since the specific resistance of No. 2, from m to g, is (6) 137500; and that of No.

3 is (6) 15625; and of these routes acting jointly, (7) 36607; in each instance from m to g; by [70]

$$140{,}30 \sqrt{\frac{(7)\ 36607}{(6)\ 1375}} = 7{,}239 \text{ as the quantity in No. 2 route}$$

and

$$14{,}030 \sqrt{\frac{(7)\ 36607}{(6)\ 1375}} = 6{,}791 = \text{the quantity in No. 3 split,}$$

their sum being 14,030 = the quantity passing from b to m as above.

And similarly, having found 16,844 cubic feet to be the quantity passing from a to g *via* splits Nos. 4 and 5; and the specific resistance of No. 4 route (6) 640,925, and of No. 5 (6) 1875, their united operation reducing it to (7) 78971; so that, by [70],

$$16{,}844 \sqrt{\frac{(7)\ 78{,}971}{(6)\ 640{,}925}} = 5{,}913 = \text{cubic feet per minute in No. 4 split, from a to g}$$

and

$$16{,}844 \sqrt{\frac{(7)\ 78{,}971}{(6)\ 187{,}5}} = 10{,}931 = \text{cubic feet per minute in No. 5 split, from a to g}$$

Their sum being .. 16,844, as before found.

We have therefore determined the quantities in each of the splits to be as follows:—

	Cubic Feet per Minute.
In No. 1 split from b to x	= 7,995
In No. 2 split from m through n to g	= 7,239
In No. 3 split from m through l, y, to g	= 6,791
In No. 4 split from a through w, v, d, e, f, r, to g ..	= 5,913
In No. 5 split from a through e, h, i, k, y to g	= 10,931
Giving as the total quantity of air in the mine	38,869

cubic feet per minute, as already stated.

The sum of the quantities in Nos. 1, 2, and 3 routes, = 22,025 cubic feet, traverses the passage from a to b. The sum of the quantities in Nos. 2 and 3 routes passes from b to m, and is 14,030 cubic feet.

The sum of the splits Nos. 2, 3, 4, and 5 passes from g to x, and is 30,874 cubic feet per minute.

The total quantity of air in the mine, 38,869 cubic feet per minute, passes down the downcast shaft at a, and also from x, through z, and up the upcast shaft.

It can be shewn that the pressure required to overcome the resistances encountered by each particular split of air, considered in its passage from the top of the downcast shaft, to its reaching the top of the upcast shaft will be of equal amount.

Since the conditions we have supposed, presume that the air is neither accelerated nor retarded by the gravitation of the air in the workings of the mine, and only the gross ventilating pressure operates in each route; it results that [67] the square of the quantity of air, in cubic feet per minute, circulating in each route, or part of a route, multiplied by the specific resistance of such route, or part of a route, will give the total height of air column required to overcome the resistances encountered, and to propel such air through such route, or part of a route; and therefore, the sum of all the resistances, so found, for any particular quantity of air (from its entering the downcast, up to its being expelled from the top of the upcast shaft,) will be the total ventilating pressure employed; expressed in feet of air column.

Taking first the air in No. 1 split; it, in common with that in all the other splits, encounters the resistance of the downcast shaft, and also that offered by the furnace, furnace drift and upcast shaft.

The specific resistances of the parts in question consist of,

That of the downcast shaft.....	(7) 11,725
From x through upcast shaft	(7) 35,175
Or, on the whole	(7) 46,900

and hence the pressure absorbed by these passages is $38,869^2 \times (7)\ 46,900 = 70{\cdot}856$ feet of air-column.

The air in No. 1 route encounters, in common with that in Nos. 2 and 3 routes, a further resistance in passing from a to b, $22,025^2 \times (7)\ 31,250 = 15{\cdot}159$ feet of air-column; the specific resistance of this portion of the air-ways being (7) 31,250, and the sum of the quantities of air in these routes being 22,025 cubic feet per minute.

The air in No. 1 route encounters alone, from b, through c, to p, a specific resistance of (6) 218,750; and a further specific resistance of (9) 600 in passing from p, through q, to x; or of (6) 219,350, on the whole; the quantity of air in the split being 7,995 cubic feet per minute; and hence these portions of air-way require, $7,995^2 \times (6)\ 219,350 = 14{\cdot}021$ feet of air-column to propel the air through them.

The entire pressure in feet of air-column, due to the circulation of the air in No. 1 route, will, therefore, consist of the pressures due to,

Shafts, furnace, and furnace drift	=	70·856
From a to b.....	=	15·159
From b through c, p and q to x	=	14·021
Or on the whole the pressure is		100·036

feet of air-column; which, but for errors due to fractions, would have been exactly 100 feet. In Nos. 2 and 3 routes or splits, the air, besides encountering the resistances in the shafts, furnace, and furnace drifts, together with that of the air-way extending from a to b, also meets with the resistance of the air-way from b to m, whereof the specific resistance is (9) 200; the pressure expended, $14{,}030^2 \times$ (9) 200 = .039 feet of air-column.

The air in No. 2 route also encounters alone, the resistance arising in the passage from m through n, to g; the specific resistance being (6) 137,500, and the air 7,239 cubic feet per minute; requiring a pressure of $7{,}239^2 \times$ (6) 137,500 = 7·205 feet of air column.

The specific resistance of the air-way from g to x is (8) 7,050, and is traversed by the air in Nos. 2, 3, 4 and 5 routes or splits, amounting to 30,874 cubic feet per minute: the pressure expended on the resistance is therefore, $30{,}874^2 \times$ (8) 7,050 = 6·720 feet of air column.

On the whole, the resistance due to No. 2 split requires a pressure composed of,

Shafts, furnace, and furnace drift	=	70·856
From a to b as in No. 1 split	=	15·159
From b to m.....	=	0·039
From m through n to g	=	7·205
From g to x.....	=	6·720
Or, on the whole the pressure is		99·979 feet

of air column; which, but for fractions, should have been 100 feet; from which, it will be perceived, it differs in a very slight degree.

The air-way extending from m through l to g, has a specific resistance of (6) 156,250, and is traversed by the air of No. 3 split alone, and therefore absorbs a pressure of, $6{,}791^2 \times$ (6) 156,250 = 7·206 feet of air column.

The entire resistance encountered by the air in No. 3 split, therefore, arises as follows:—

Shafts, furnace, and furnace drift	=	70·856
From a to b.....	=	15·159
From b to m	=	0·039
From m through l to g	=	7·206
From g to x.....	=	6·720
Amounting in all to		99·980 feet

of air-column.

The specific resistance of the air-way extending from a through w, r, d, and f, to g, is (6) 640,925, where it is traversed only by the air in No. 4 split; the entire pressure required to overcome the whole of the resistances encountered by such air, consists of that due to the above or

$5{,}913^2 \times (6)\ 640{,}925$	=	22·409
Shafts, furnace, and furnace drift	=	70·856
From g to x	=	6·720
Giving as the entire pressure expended.....		99·985

feet of air column; again approaching very closely to the ventilating pressure of 100 feet.

In No. 5 split, we have the specific resistance of the air-way extending from a through e, h, i and k to g, equal to (6) 187,500; where there is 10,931 cubic feet of air per minute, or the mere quantity due to No. 5 split; requiring therefore a pressure of $10{,}931^2 \times (6)\ 187{,}500 = 22{\cdot}404$ feet of air column. The entire pressure due to this air consisting of,

Shafts, furnace, and furnace drift	=	70·856
From a through e, h, i and k to g.....	=	22·404
From g to x	=	6·720
Amounting on the whole to		99·980

feet of air-column; a very near approximation to the entire ventilating pressure of 100 feet.

Collected, therefore, we have the pressures due to each of the splits, as below; where the errors arising from the fractions, and from the difference between the true quantity, and the approximation to the quantity of air passing out of No. 1 split, through Nos. 2 and 3 routes, are exhibited—

	Pressures in feet of air column.	Errors in the calculations.
No. 1 split	100·036	+ ·036
No. 2 do.	99·979	— ·021
No. 3 do.	99·980	— ·020
No. 4 do.	99·985	— ·015
No. 5 do.	99·980	— ·020

So that the calculated pressures, in no case, differ from the assumed ventilating pressure of 100 feet of air column by more than 1-2,777th part; affording sufficient evidence of the general correctness of the calculations.

It may be seen, that when only 20,649 cubic feet of air per minute were circulating, before the change of air was supposed to be effected, in the foregoing example, there was required a pressure of 80 feet of air column, to drive this quantity of air through the workings of the mine; leaving only 20 feet of air-column to overcome the resistances of the shafts and undivided air-ways at the furnace and furnace drift; the effect of the change of air being to reduce the expenditure of pressure on the workings, to 29·144 feet of air column, even on the increased quantity of air; thus leaving, out of an equal gross ventilating pressure, 70·856 feet of air-column to overcome the resistances encountered by the air in the shafts, furnace and furnace drift; and hence the great increase in the quantity of air put into circulation in a given time, after making the change of air.

The preceding results plainly indicate the great benefit arising to ventilation from reducing, virtually, the specific resistances of the air-ways of a mine, by ventilating them, as far as may be safely practicable, with a number of distinct splits of air.

If the ventilating pressure were independent of the area of the shafts and undivided air-ways near them, they should be made of the greatest practicable area, to ensure the best results in ventilation. This is the case with reference to a downcast shaft and all level air-ways, whatever may be the power employed; but when furnace ventilation happens to be the power made use of, there will probably exist a limit to the area of the furnace drift and upcast shaft, to exceed which would operate prejudicially on the ventilation of the mine, all other things being the same; inasmuch as the cooling of the air, in the air-ways and shafts, traversed by it after passing over the furnace, will become greater, and greater, as we enlarge their area, and thereby reduce the ventilating pressure.

At the same time any enlargement of these air-ways must be attended with a reduction of their specific resistance, which would be to set against the increased loss by cooling; these, in fact, are leading elements for consideration in determining what is the best possible area of section to be given to upcast shafts, in order to realize the maximum ventilation by the consumption of a given quantity of fuel, when the power employed is that of furnaces. The specific resistance offered by the downcast shaft and workings would, however, also require consideration in

determining this much disputed question; and since the amount of the specific resistances of the air-ways would not remain constant, in the same mine, for any great length of time, the upcast shaft could not remain of the best possible area for any longer period; yet it is possible that it might be so little effected by changes in these resistances as practically, if not scrupulously, to do so; and therefore the matter appears to be one well worthy of a strict investigation.

A general examination of the example given in the preceding part of this chapter will show that in order to be able to determine, *a priori*, the exact quantity of air which will circulate in each split under any given or assumed ventilating pressure, it is necessary to ascertain the specific resistances of each separate part of the shafts and air-ways, which are to be traversed by quantities of air of different amounts, and then to put the results into the form of equations, on the principle of the barometrical pressure of the air at all the points of separation and reünion of the splits of air being of equal amount, for each of the splits so separating, or uniting; while the total expenditure of pressure per unit of surface, must be equal to the entire general ventilating pressure employed, except in so far as the effects of the gravitation of the air in any of the ascents or descents traversed by the air, having different temperatures and densities, may operate to render the pressures required in some of the splits, greater or less than in others; in cases where these causes of discrepancy exist it will become necessary to introduce constants into the equations, representing the pressures generated, or absorbed, in each route or split of air; and then to determine by them, the quantities of air due to each split, when some definite pressure is employed to produce ventilation; as in such cases, the *proportions* in which the air will divide itself over the different splits will vary with the amount of general ventilating pressure employed, and consequently with the total quantity of air put into circulation in a given time.

As this communication has already extended itself to perhaps too great an extent, it is not considered worth while giving any particular example to illustrate a case of the above character.

APPENDIX.

A.—*Note on certain Formulæ for finding the Velocity of Air in Pipes, &c.*

When the form and dimensions of the section of any pipe, flue, or air-way, happen to be uniform throughout the extent of the passage, a constant may be found, of such value, that if the velocity which would have prevailed in the absence of resistances be multiplied by it, the quotient will be the actual velocity.

Adopting the following notation—

h = height in feet of head of air column, equal to the pressure employed;

V = velocity in feet per minute, due to the head h, if there were no resistances;

v = actual or observed velocity in feet per minute;

L = length in feet of pipe, flue, or air-way;

c = perimeter of section of air-way, in feet;

Q = cubic feet of air per minute;

A = area of section of air-way, in superficial feet;

m = constant multiplier for any given air-way, being the ratio of v to V, so that $m = \frac{v}{V}$;

D = diameter of pipe, flue, or air-way, in feet, when the section is circular; or the side of the section of the same when it is square;

π = 3·1416, the ratio of the circumference to the diameter of a circle.

Then, by [54] and [63],

$$h = \frac{k\,L\,c\,Q^2}{A^3} + \frac{Q^2}{231600\,A^2} \quad \text{[a]}$$

and hence,

$$h = \frac{Q^2}{A^2}\left\{\frac{k\,L\,c}{A} + \frac{1}{231600}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{[b]}$$

and also,

$$v = \frac{Q}{A} = \sqrt{\frac{h\,A}{k\,L\,c + \frac{A}{231600}}} \quad \ldots\ldots\ldots\ldots\ldots \text{[c]}$$

In the absence of resistances, by [10], the velocity due to the head of air column, h, would have been

$$V = \sqrt{231600\,h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{[d]}$$

but by our notation

$$m = \frac{v}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{[e]}$$

and by substituting in [e], the value of v in [c], and that of V in [d], we obtain,

$$m = \sqrt{\frac{\frac{h\,A}{k\,L\,c + \frac{A}{231600}}}{231600\,h}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{[f]}$$

which is reducible to

$$m = \sqrt{\frac{A}{231600\,k\,c\,L + A}} \quad \ldots\ldots\ldots\ldots\ldots \text{[g]}$$

and since $v = V\,m$; and also $V = \sqrt{231600\,h}$

$$v = \sqrt{231600\,h} \times \sqrt{\frac{A}{231600\,k\,c\,L + A}} \quad \ldots\ldots\ldots\ldots \text{[h]}$$

which is the general equation for the velocity v.

When the form of section is a circle $D^2\frac{\pi}{4} = A$; and $D\,\pi = c$; which values of A and c being substituted in [g], gives

$$m = \sqrt{\frac{D^2\frac{\pi}{4}}{231600\,k\,D\,\pi\,L + D^2\,\frac{\pi}{4}}} = \sqrt{\frac{D}{231600 \times 4\,k\,L + D}}$$

which may be expressed thus,

$$m = \sqrt{\frac{1}{231600 \times 4\,k}} \times \sqrt{\frac{D}{L + \frac{1}{231600 \times 4\,k} D}} \; ; \; \ldots . [i]$$

when the form of section happens to be a square $D^2 = A$, and also $4\,D = c$; and by substituting these values of A and c, in [g], we obtain

$$m = \sqrt{\frac{D^2}{231600 \times 4\,k\,D\,L + D^2}} = \sqrt{\frac{D}{231600 \times 4\,k\,L + D}}$$

which may be expressed thus,

$$m = \sqrt{\frac{1}{231600 \times 4\,k}} \times \sqrt{\frac{D}{L + \frac{1}{231600 \times 4\,k} D}} \; \ldots . [k]$$

by which we see that the multiplier, m, has the same value in [i], as in [k]; that is, it is the same, whether the section be circular or square; in either case the actual velocity is

$$v = \sqrt{231600\,h} \times \sqrt{\frac{1}{231600 \times 4\,k}} \times \sqrt{\frac{D}{L + \frac{1}{231600 \times 4\,k} D}} \; \ldots . [l]$$

By calculating the values of $\frac{1}{231600 \times 4\,k}$, and also the square roots of the same, for the various values of k, given in Table 1, we have

Nature of Material composing interior surface of air-way.	State of the Air.	Values of k.	Corresponding values of $\frac{1}{231,600 \times 4 \times k}$	Corresponding values of $\sqrt{\frac{1}{231,600 \times 4 \times k}}$
Clean Bricks or Pottery....	Hot.	·000,000,268,810	4·0157	2·0039
Old Tarred Cast Iron.....	Cool.	·000,000,019,050	56·664	7·5275
Old Rusty Sheet Iron.....	Cool.	·000,000,027,517	39·228	6·2633
Tinned Iron	Cool.	·000,000,025,400	42·498	6·519
Cast Iron, covered with soot	Hot.	·000,000,052,917	20·399	4·5165
Clean New Sheet Iron.....	Hot.	·000,000,105,830	10·2	3·1937

By substituting, successively, the tabulated values of $\frac{1}{231600 \times 4 \times k}$ and $\sqrt{\frac{1}{231600 \times 4 \times k}}$, in [l], we obtain the following formulæ for the passage of air through pipes, flues, or air-ways, having an uniform and equal, square or circular section; when D is the side of the square, or the diameter of the circle, as the case may be; and v the velocity in feet per minute.

According to Péclet, when the material is Burnt Earth, (brick) or Pottery,—new, clean, and free from soot; the air being heated.	$v = \sqrt{231{,}600\ h} \times 2{\cdot}0039 \sqrt{\frac{D}{L + 4{\cdot}0157\ D}}$	.... [m]
According to Girard, when the material is Cast Iron,—after long use, and tarred or pitched; the air being cool.	$v = \sqrt{231{,}600\ h} \times 7{\cdot}5275 \sqrt{\frac{D}{L + 56{\cdot}664\ D}}$	.... [n]
According to Girard, when the material is Rusty Sheet Iron; and the air cool.	$v = \sqrt{231{,}600\ h} \times 6{\cdot}2633 \sqrt{\frac{D}{L + 39{\cdot}228\ D}}$	.... [o]
According to Daubuisson, when the material is Tinned Sheet Iron; and the air cool.	$v = \sqrt{231{,}600\ h} \times 6{\cdot}519 \sqrt{\frac{D}{L + 42{\cdot}498\ D}}$	.... [p]
According to Péclet, when the material is Cast Iron,—after long use as a chimney, and covered with soot; the air being heated.	$v = \sqrt{231{,}600\ h} \times 4{\cdot}5165 \sqrt{\frac{D}{L + 20{\cdot}399\ D}}$	.... [q]
According to Péclet, when the material is New Sheet Iron,—free from rust and soot; and the air heated.	$v = \sqrt{231{,}600\ h} \times 3{\cdot}1937 \sqrt{\frac{D}{L + 10{\cdot}2\ D}}$	.... [r]

The first of the preceding series of formulæ, [m], which answers to the passage of heated air through an air-way, exposing to the moving air a surface of burnt earth (brick) or pottery, new, clean, and free from soot, may be considered as being identical with that which Mr. G. C. Greenwell ascribes to Mons. Péclet, and which he found to agree very closely with an experiment made by himself, to ascertain the resistance encountered by air passing down the downcast shaft, through a gallery forming a part of the underground workings of the Crook Bank Colliery,

and, after being heated by passing over a ventilating furnace, up the upcast shaft.

The formula in question would, in the notation here employed, stand thus

$$v = \sqrt{231{,}600\ h} \times 2{\cdot}06 \sqrt{\frac{D}{L + 4\ D}} \cdots\cdots\cdots\cdots\cdots\cdots [s]$$

the constants in which differ slightly from those given in the preceding formula [m], the cause of which I have not ascertained.

It may, however, be proper to state, that although I do not perceive any formulæ of the form of the above, in M. Péclet's "Traité de la Chaleur," third edition, 1844; the only work by M. Péclet in my possession; yet I observe that Mons. M. P. Berthier in his "Traité des Essais par la voie sèche," exhibits a formula agreeing with [s], which he ascribes to M. Péclet.

The formulæ given in this memoir, in relation to the subject here under consideration, have been constructed from the general laws ascertained to prevail, in experiments made by different persons, as recited in Chapter I; the constants depending on the value of the coefficients of resistance k, being deduced from those given by Mons. Péclet in the work already alluded to; where the coefficients are 47,245 times greater than are suited to the formulæ here given, so that this has been accomplished by dividing the constants given by M. Péclet, by that number; which arises from the continued multiplication of the number of English feet in a French metre, 4, and the square of the number of seconds contained in a minute, (3,600), into each other; thus,

$$3{\cdot}2809 \times 4 \times 60^2 = 47{,}244{\cdot}96.$$

II.—*Note on the Coefficient of Resistance due to Steam in Pipes.*

It may be interesting to know, that from an experiment made by Mons. Rudler, M. Péclet deduces two limits of the value of the coefficient of resistance encountered by steam in passing through a pipe, one being ·0032, and arises on the presumption of the escaping steam expanding to the volume due to the pressure of the atmosphere; and the other ·004, which arises out of the experiment, on the supposition of the steam having escaped at the pressure and volume due to the steam in the boiler, which was loaded above the atmospheric pressure to the extent of $0{\cdot}^{m}2$ of mercury.

These quantities would give the pressure of the steam, over that of the atmosphere, as $39{\cdot}3708 \times 0{\cdot}^{m}2 = 7{\cdot}8741$ English inches of mercury; and the coefficient of resistance k (as suited to the formulæ in this memoir) as being

$$k = \frac{{\cdot}0032}{47245} = {\cdot}000{,}000{,}067{,}73$$

if the steam escaped with the volume due to the pressure in the boiler, without undergoing expansion; but if, on the contrary, the steam be supposed to have escaped in an expanded state, at the pressure due to the atmosphere, then, from this experiment

$$k = \frac{{\cdot}004}{47{,}245} = {\cdot}000{,}000{,}084{,}66$$

and hence the actual value of k, in this experiment, may be considered as lying between these limiting values.

M. Péclet does not state what was the nature of the material composing the escape-pipe used in M. Rudler's experiment, as he concludes, I fear on too slight grounds for reliance, that the resistance encountered by steam flowing through pipes, will not vary, as in the case of air, with the nature and state of the interior surface of the pipe; presuming that the steam will move against a thin film of water, adhering to the inner surface of the pipe, arising from the condensation of the flowing steam, and consequently rendering the coefficient of resistance independent of the nature and state of the material composing the conducting pipe.

It appears rather surprising, that more numerous and decisive experiments have not been made, to determine the coefficient of resistance due to steam moving through pipes; seeing that it bears so closely on the proper working of steam engines.

III.—*Note on a Formula relative to the Flow of Gas through Pipes, by Mr. Hawksley, of Liverpool.*

Our worthy President, in laying before the members of this Institute, the result of his numerous and valuable experimental inquiries into the relative value of the Furnace and Steam Jet in the ventilation of Coal Mines, notices a formula for finding the velocity of gas, flowing through gas-pipes, which Mr. Hawksley, of Liverpool, is said to have deduced from experiments on gas conveyed in pipes many miles in extent.

The formula in question is

$$v = 96 \sqrt{\frac{\left(\frac{T - t}{T + 448}\right) D s}{l m + 360 s}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [t]$$

Where

v = velocity of gas in feet per second.
T = average temperature of upcast shaft.
D = depth of upcast shaft in feet.
t = temperature of downcast shaft.
s = sectional area of air-courses in feet.
m = perimeter of section of air-courses in feet.
l = length of air-courses in feet.

Now, in the above, $\left(\frac{T - t}{T + 448}\right) D$ is evidently the pressure, per unit of surface, employed; expressed in height of gas-column, in feet; and is, therefore, equivalent to our symbol h, as used in this Appendix.

Again, s in the above, is identical with our symbol A; m is the same as our c; l in Mr. Hawksley's formula, agrees with our L; and v in Mr. Hawksley's formula, since it relates to the velocity in feet *per second*, is only one-sixtieth part of the value of the same letter in this Appendix, which expresses the velocity in feet *per minute*.

By replacing Mr. Hawksley's symbols with those we have already used, his formula becomes

$$v = 96 \sqrt{\frac{h A}{L c + 360 A}} \times 60$$

or

$$v = 5760 \sqrt{\frac{h A}{L c + 360 A}}$$

In order to make this latter equation correspond with our equation [c], it is only necessary to multiply that part of the right hand member which is not embraced by the radical sign, by $\sqrt{k}$; and, (thus preserving the value of the expression) to divide the remaining part of the expression by the same, or by $\sqrt{k}$, giving

$$v = 5760 \sqrt{k} \sqrt{\frac{h A}{k L c + 360 k A}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [u]$$

and since, by [c],

$$v = \sqrt{\frac{h\,A}{k\,L\,c + \frac{A}{231600}}}$$

we ought to have,

$$5760\ \sqrt{k} = 1$$

and hence,

$$k = \frac{1}{5760^2} = \cdot 000,000,030,14 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ [v]$$

If, in Mr. Hawksley's experiments, the gas escaped without suffering any contraction of the flowing vein, and if there were no other resistances to overcome than that of friction, as due to the pipes, we ought also to have had,

$$360\ k = \frac{1}{231,600}$$

and hence, in that case

$$k = \frac{1}{360 \times 231,600} = \cdot 000,000,011,994 \ldots\ldots\ldots [w]$$

This discrepancy between the two values of the coefficient of resistance, as deduced from Mr. Hawksley's formula, admits, in all probability, of being explained in one of two ways; both indicating that the actual value of k, as suited to our formulæ, and derived from Mr. Hawksley's observations, is nearly expressed by ·000,000,030,14.

In the first place, if we suppose that no pressure was expended, excepting that due to the velocity v, and the frictional resistance, yet if the pipes exposed an extensive rubbing surface in proportion to the area of their section, in other words, if l c was very great in proportion to A, then the formula given by Mr. Hawksley would not sensibly differ from observation, because the denominator of the fraction under the radical sign would not be materially increased by multiplying the small quantity A, denoting the area of the pipe, by 360, instead of multiplying it by a smaller, and more correct multiplier.

The multiplier according to the investigations contained in the preceding part of this memoir, on taking the value of k at ·000,000,030,14, would be

$$\frac{1}{231,600 \times \cdot 000,000,030,14} = 143\cdot 26$$

instead of 360; presuming there to have been no expenditure of pressure

beyond that due to the velocity in the pipe, and the corresponding frictional resistances.

If, on the other hand, Mr. Hawksley's formula were applied to pipes of short length, and presenting little rubbing surface in proportion to their diameter, so far as we can rely upon the results obtained by Péclet, Girard, and Daubuisson, it would indicate less than the real velocities; unless, indeed, there happened to be an expenditure of pressure at a contraction of the flowing vein, for which no allowance were made in the calculation; a circumstance, perhaps not unlikely to have occurred, and which might have the effect of accounting for Mr. Hawksley having adopted the large coefficient of 360, instead of 143, as theory, and the experiments of other persons, would indicate to be required, on the presumption that ·000,000,030,14 is the value of k, as suited to ordinary gas pipes.

These remarks may be illustrated in the following manner; suppose we apply the formula [u], corresponding in value with that of Mr. Hawksley, to determine the velocity due to gas flowing under a pressure of 130 feet of gas-column, through a pipe 500 yards, or 1500 feet in length, and 6 inches, or ·5 of a foot in diameter; presuming the coefficient of resistance k to be ·000,000,030,14: we obtain,

$$v = 5760 \times \sqrt{\cdot 000{,}000{,}030{,}14}$$

$$\times \sqrt{\frac{130 \times \cdot 5^2 \times \cdot 7854}{\cdot 000{,}000{,}030{,}14 \times 1500 \times \cdot 5 \times 3\cdot 1416 + 360 \times \cdot 000{,}000{,}030{,}14 \times \cdot 5^2 \times \cdot 7854}}$$

$= 590\cdot 72$ feet per minute.

In the above example, if we had used the number 143·26, instead of Mr. Hawksley's constant, 360, we should have obtained the velocity as 595·97 feet per minute, which only exceeds that given by Mr. Hawksley's formula, by about 1 per cent. of its amount.

As previously stated this discrepancy would be greater, as the length of pipe is lessened, and its diameter increased; but the existence of a *vena contracta*, either at the entrance, or exit ends of short pipes experimented upon, if no direct allowance were made for their effects, would be likely to lead Mr. Hawksley to conclude that 360 ought to be the constant used in all cases; if indeed it was determined in an empirical manner from experiments.

If we consider, therefore, that ·000,000,030,14 is the value of the coefficient of resistance encountered by gas or air flowing through ordinary gas pipes, (of cast iron ?) we see that it is about 10 per cent. greater than

the same coefficient, in the case of rusty sheet iron pipes, as determined by M. Girard; and even 50 per cent. greater than in the case of cast iron pipes, *coated internally with tar or pitch;* a fact which almost induces one to suppose that the ventilation of mines, may hereafter come to be improved by coating the principal air-ways, but more particularly the shafts, with some substance, offering less resistance of a frictional nature, than the ordinary bare walls generally present to the passage of the air.

IV.—*Note on the Discharge of Water through Pipes having a Circular Section.*

The formula given by Eytelwein for finding the velocity with which water flows through a pipe is,

$$v = 26{\cdot}44 \sqrt{\frac{P\,D}{L + 54\,D}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [x]$$

where

v = the velocity in French metres, per second.
P = the height of head of water-pressure, in metres.
D = the diameter of the pipe, in metres.
L = the length of the pipe, in metres.

The above formula, on being so modified as to express by v, the velocity in feet per minute; by h, the height of head of water, in feet; by D, the diameter of the pipe, in feet; and by L, the length of the pipe, in feet; becomes,

$$v = 2873{\cdot}5 \sqrt{\frac{h\,D}{L + 54\,D}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [y]$$

and may also be written or expressed thus

$$v = \sqrt{231600\,h} \times \frac{2873{\cdot}5}{\sqrt{231600}} + \sqrt{\frac{D}{L + 54\,D}} \quad \ldots\ldots\ldots\ldots [z]$$

and since $\frac{2873{\cdot}5}{\sqrt{231600}} = 5{\cdot}9709$,

from what has been stated in a previous part of this Appendix, it may be seen that in this instance,

$$\sqrt{\frac{1}{231600 \times 4\,k}} = 5{\cdot}9709, \text{ and consequently}$$

$$k = \frac{1}{231600 \times 4 \times 35{\cdot}652} = {\cdot}000{,}000{,}030{,}278$$

which is the value of the coefficient of resistance in the case of water, as suited to any of the formulæ contained in this memoir; a coefficient, found by experience, to be constant for water, whatever may be the nature or state of the internal surface of the pipe or passage, in which it flows.

According, however, to the formulæ given by the authorities previously alluded to, we ought also, in this case, to have had

$$\frac{1}{231600 \times 4 \times 54} = k = \cdot 000,000,019,989$$

which is only about two-thirds of the value of the same coefficient, as found from the preceding and more important part of the formula.

The more correct value ·000,000,030,278, of k, will, from the nature of the formula, be found to give results closely agreeing with practice, in any of the formulæ which are given in this memoir: the number 54, occurring in the denominator of the fraction under the $\sqrt{}$, being probably too high, arising from the same causes as have been suggested for a similar occurrence, in the case of Mr. Hawksley's formula, for the passage of gas through ordinary gas pipes: indeed, it seems a little remarkable that Mr. Hawksley's constant, for gas in pipes, agrees so closely with the above, as due to water, according to the formula of Eytelwein; the former being ·000,000,030,14, and the latter ·000,000,030,278, while each of them give the multiplier, before alluded to, considerably greater than reasoning would indicate, and than has been found by other persons to agree with practice and experiments.

V.—*Note on the prevailing Ideas of Gas Engineers on the Discharge of Gas through Pipes.*

In the "*Mechanics' Magazine*," No. 1368, of Saturday, October 27, 1849; a letter appears, of which the following is a copy:—

FLOW OF GAS THROUGH PIPES.

SIR,—In no department of gas engineering is there more need of experimental information than in that of the flow of gas through pipes, inasmuch as the results given us by rule do not agree with those found in practice.

I believe that the same inconsistency holds in regard to the flow of water and other fluids; but my experience being confined to gas, I will limit my observations to that branch of the subject.

I have read the best works upon the subject, and had the private opinions of the most eminent engineers, and, with one exception, I have been told that for the difference

of length, the discharge will be inversely as the square roots of the lengths, and that, for different diameters, the discharge will be directly as the squares of the diameters.

To take an instance:—A pipe, 6 inches in diameter and 500 yards long, is found to deliver 3,686 cubic feet; whereas the same pipe, if extended to 1000 yards in length, will only deliver 2,606 cubic feet. This has been proved by experiment, and we will assume it to be correct.

But we are told that a pipe, 12 inches in diameter and 500 yards long, will deliver only 14,744 cubic feet; or, if extended to 1000 yards in length, its discharge will be reduced to 10,424 cubic feet. In both cases it will be observed that the amount said to be delivered by the 12-inch pipe is exactly four times that delivered by the 6-inch pipe, or as the square of the area (*diameter?*); and here I disagree with those who have written before me.

In a calculation of this kind there are involved a great many intricacies; but I will pass over those minor considerations, such as the friction of the particles one against another, &c., which theory, perhaps, more than practice, would lay stress on, and merely advert to what appear to be the main causes requiring notice, namely, the gravitating power or inertia of the gas and the surfaces against which it has to rub during transmission, these having to be overcome by the force or pressure employed.

Let us see then how this applies in the case before us. A pipe, 6 inches in diameter, is, in circumference, 18·8496 inches; and four such pipes equal in capacity to one 12-inch pipe, are in circumference 75·3984. Now, a pipe 12 inches in diameter is, in circumference, 37·6992 inches, or just one-half; so that in one case we have double the rubbing surface which we have in the other. Under such circumstances, I pronounce it physically impossible that the discharge can be the same.

I am aware that some modern writers have remarked that there will be a slight advantage in favour of the larger pipe, from the cause I have just mentioned; but I contend that a passing notice of such an important point is not enough, inasmuch as large pipes, from 12 to 16 and 18 inches in diameter, will deliver from 40 to 70 or 80 per cent. more than the rule gives.

We have found that when the 6-inch pipe was 500 yards in length, it delivered 3,686 cubic feet, and when extended to 1000 yards in length, its delivery was reduced to 2,606 cubic feet. Now, in thus extending the pipe, what did we do? Why, increase the rubbing surface. We thus have a rule for calculating the effect of length friction, while side friction is entirely overlooked, just as if there was any important difference between the one and the other.

For the reasons above stated I have been led to add one additional rule, viz., *that the discharge will be inversely as the square root of the rubbing surface.* A 12-inch pipe, therefore, will deliver at 1000 yards length 14,731 cubic feet, an addition of 41 per cent. The difference appears more conspicuous in very large pipes; thus an 18-inch pipe is reckoned to deliver, at 1000 yards, 23,454 cubic feet, whereas, by my calculation, it will deliver 40,677 cubic feet.

I am not able to say that I have proved this rule by experiments expressly made for the purpose; nevertheless, I am prepared to say that it agrees with my experience of the action of large pipes better than any other rule I can apply. I therefore throw it before your readers to receive their scrutiny, and shall be happy to hear of any rule that will answer existing objections better.

October 18, 1849. GEO. ANDERSON.

The rule proposed by Mr. Anderson in the text of the preceding letter, it may be observed, does not agree with the rule by which he has made the calculations given in the letter, if even we admit, as we evidently must, that he has used the expression, "or as the square of the area," when he really intended it to have been, "or as the square of the diameter;" because the latter expression agrees with the context, while the former is at variance with it.

If by Q we denote the quantity of gas discharged in the unit of time, by D the diameter of the pipe, by c its circumference internally, and by L its length, each in the case which is taken as a datum, having been proved by experiment; and if we further denote by Q the quantity in any other case, in which D is the diameter, C the perimeter of section, and L the length of the pipe; then, according to the statement in the letter, the ordinary and erroneous rule gives

$$Q = \frac{D^2}{\mathrm{D}^2}\sqrt{\frac{\mathrm{L}}{L}}\,\mathrm{Q}$$

But in a pipe, it is evident that the rubbing surface is represented by the product of the length and the circumference of the section of the pipe; and since Mr. Anderson professes to have been led to *add* to the above erroneous rule, by way of rendering it correct, an additional rule, viz., that the discharge will be inversely as the rubbing surface; we should have for his new rule,

$$Q = \frac{D^2}{\mathrm{D}^2}\sqrt{\frac{\mathrm{L}}{L}}\sqrt{\frac{\mathrm{L\,c}}{L\,C}}\,\mathrm{Q} = \frac{D^{1\frac{1}{2}}}{\mathrm{D}^{1\frac{1}{2}}}\frac{\mathrm{L}}{L}\,\mathrm{Q}$$

This rule, however, does not agree with the calculations given by Mr. Anderson in his letter; he has in fact made his calculations upon the more correct principle of the discharge being directly proportional to the cube of the diameter, and inversely to the square root of the rubbing surface; which gives a rule expressed thus,

$$Q = \frac{D^3}{\mathrm{D}^3}\sqrt{\frac{\mathrm{L\,c}}{L\,C}}\,\mathrm{Q} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [A]$$

a rule which would be correct, and in accordance with the formulæ in this memoir, were it not that it omits to take cognizance of the pressure due to the generation of velocity; and whenever the pressure expended on the creation of velocity is a small proportion of the entire pressure employed, the rule will give results nearly agreeing with those given by the formulæ in this memoir.

In Mr. Anderson's datum case, where the discharge was 3,686 cubic feet per hour, or 61·43 cubic feet per minute, the pipe was 6 inches or ·5 of a foot in diameter, and 500 yards or 1,500 feet long; and if we assume the coefficient of resistance (as due to the formulæ in this memoir) to have been ·000,000,030,14, as deduced from Mr. Hawksley's experiments, we should have for the entire pressure employed, in feet of gas column; expressing it by P,

$$P = \frac{61{\cdot}43^2}{({\cdot}5^2 \times {\cdot}7854)^2}\left(\frac{{\cdot}000{,}000{,}030{,}14 \times 1{,}500 \times {\cdot}5 \times 3{\cdot}1416}{5^2 \times {\cdot}7854} + \frac{1}{231{,}600}\right)$$

or,

$$P = 35{\cdot}828 \text{ feet.}$$

Letting A = area of section of pipes in superficial feet.

Q = the discharge in cubic feet per minute.

π = 3·1416 the ratio of the circumference to the diameter of a circle.

D = the diameter of the pipes in feet.

L = the length of the pipes in feet.

g = the velocity in feet per minute, acquired by a body falling one minute under the force of gravity = 115,800.

k = the coefficient of resistance, or the height of gas column required to overcome the friction on one superficial foot area of rubbing surface, when the velocity is one foot per minute; in this instance taken at ·000,000,030,14.

By the formulæ used in this memoir

$$Q = \sqrt{\frac{P\,A^3}{k\,L\,c + \frac{A}{2g}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [B]$$

and since $A = D^2 \frac{\pi}{4}$; and also $c = D\,\pi$, when the section of the pipes is circular, we have,

$$Q = \sqrt{\frac{P\,\frac{\pi}{4}\,D^5}{4\,k\,L + \frac{D}{2\,g}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots [C]$$

and by this formula,

Q = 61·43 when D = ·5 and L = 1,500
Q = 43·569 when D = ·5 and L = 3,000
Q = 34·549 when D = 1 and L = 1,500
Q = 245·73 when D = 1 and L = 3,000
Q = 675·17 when D = 1·5 and L = 3,000

the above values of Q being multiplied by 60 will give the discharges in cubic feet per hour, as due to the formulæ in this memoir; and this process, combined with the use of the rule given in the formula [*A*], enables us to construct the following table, shewing the near agreement between the rule *used* by Mr. Anderson, and the results given by the formulæ in this memoir.

Diameter of gas pipes in feet.	Length of gas pipes in feet.	Discharge by what Mr. Anderson states to be the usual rule.	Discharge as calculated by Mr. Anderson, by formula [*A*].	Discharge by the formulæ used in this memoir [*C*].
		Cubic feet ℔ hour.	Cubic feet ℔ hour.	Cubic feet ℔ hour.
·5	1,500	3,686	3,686	3,686
·5	3,000	2,606	2,606	2,614
1	1,500	14,744	20,848	20,730
1	3,000	10,424	14,731	14,744
1·5	3,000	23,454	40,677	40,510

Dr. Ure, in his "Dictionary of Arts, Manufactures and Mines," erroneously states that the discharge from the end of a pipe is directly proportional to the square of its diameter, and inversely as the square root of its length; whereas, when all other things are constant, and the pressure expended on creating velocity is so small that it may be neglected, the discharge is proportional to the square root of the fifth power of the diameter of the pipe, or what is the same, to the diameter of the pipe raised to the power of two and one half.

In pipes where our coefficient of resistance k = ·000,000,030,14, (unless the pipes are very short), we will obtain sensibly correct results by using any of the following formulæ,

$$Q = 134{,}916 \sqrt{\frac{P}{L\,D}} \times D^{5} \ldots\ldots\ldots\ldots\ldots [D]$$

$$Q = 134{,}916 \sqrt{\frac{P\,D^{5}}{L}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots [E]$$

or in logarithms,

$$\text{Log. } Q = 5{\cdot}1300647 + \frac{\text{Log. } P + (\text{Log. } D \times 5) - \text{Log. } L}{2} \;..\; [F]$$

This may be verified by applying them to the cases given in the last Table, taking $P = 35{\cdot}828$ feet, as was done in constructing the Table, and as was necessary from the nature of the case, if we admit k to have been ·000,000,030,14.

ERRATA.

78	page,	15 lines from top, *for* pipe *read* pipes.
84	,,	11 lines from bottom, *for* [4] *read* (4).
94	,,	10 lines from top, insert a comma after the word shaft.
97	,,	8 lines from bottom, *for* equitation *read* equation.
98	,,	12 lines from bottom, *for* time *read* mine.
99	,,	insert the sign of equality = after T, in formula [34].
132	,,	19 lines from top, *for* one cubic feet *read* one cubic foot.
160	,,	5 lines from bottom, *for* downcast shaft *read* downcast column.

NORTH OF ENGLAND INSTITUTE

OF

MINING ENGINEERS.

MONTHLY MEETING, THURSDAY, FEBRUARY 8th, 1855, IN THE ROOMS OF THE INSTITUTE, NEWCASTLE-UPON-TYNE.

EDWARD POTTER, Esq., IN THE CHAIR.

The SECRETARY having read the minutes of Council the following gentlemen were elected Members:—

Dr. Richardson, Newcastle; James Hall, Stenton Iron Works, near Derby; John George Bell, Newcastle; Peter Higson, Manchester.

The CHAIRMAN begged to apologize for the absence of their worthy President, who, according to a telegraphic message sent to the Secretary, was prevented attending that day in consequence of the roads being blocked up with snow. With respect to the principal subject for consideration, viz., that of the establishment of the Mining College, he thought they would all agree in thinking that it was a very important matter to bring before the coal trade. Mr. Taylor, he knew, had some observations drawn out on the matter, but that gentleman was not inclined to submit them to the meeting without the sanction of the President. Mr. Taylor had a few minutes ago been called away on business, and he could not say whether he would be back again. He, however, begged to inform them that a meeting of the Coal Trade was held on Tuesday last, at which the subject of the Mining College was most favourably considered, and a report by the Committee of the Trade was read. The meeting unanimously passed a resolution concurring with the report

of their Committee and also with the report of the Mining Institute, as to the desirability of establishing a College for the advancement of practical mining and manufacturing science in Newcastle. As these documents were in the hands of the Secretary he would call upon him to read them to the meeting.

The SECRETARY then read the following report and resolution:—

EXTRACT FROM REPORT OF GENERAL MEETING OF THE COAL TRADE.

Newcastle-on-Tyne, Coal Trade Office, Neville Hall,
February 6th, 1855.

Your Committee now turn, not without gratification, to another topic which is unquestionably indicative of the advancing state of the trade—this is the Report of the Council of the North of England Institute of Mining Engineers on the proposed establishment of a College of Practical Mining Science, at Newcastle-upon-Tyne, laid before this Committee by that body, and now in the hands of the Members of the Trade generally. Presuming that the details of this Report are known to all present, the Committee can only proceed to impress upon the Lessees and Lessors also of Collieries and Mines the vital importance of giving the proposals, embodied in the document referred to, their best and most favourable consideration. The period has hardly arrived for the Committee to venture a conclusive opinion as to the most eligible mode of raising such funds as may be requisite to erect such an Institution, on a highly respectable and thoroughly independent foundation, and to secure its permanent utility when so established. But they may express their belief that such support cannot be safely left to spontaneous liberality. It appears to them, on the contrary, desirable that the wealthy and influential interests engaged in the great trades of raising, manipulating, and shipping the coal, lead, and iron, with which these counties abound, in all the forms and combinations which these materials are capable of entering into or assuming, together with such friends to the undertaking, out of these districts as may be disposed to aid it, should join in procuring either a Charter or an Act of Parliament, of such a nature as would, for a given number of years, secure the accruement of the funds necessary to give prosperity to the Institution, as well as such smaller permanent pecuniary aids as might, in future time, be essential to the entire utility and vitality of such an establishment. Your Committee, on the present occasion, deem it their duty to express generally, their warm approbation of the scheme, as sketched in the Report of the Council of Mining Engineers, and their hope that the great body of the Coal Trade will aid their efforts to promote, by a resolution this day, this great undertaking, for which all opinions seem to concur in pronouncing this locality to be peculiarly adapted by circumstances as well as by nature, but which is, in itself, of national rather than local importance.

RESOLVED,—That the meeting concurs in the Report of the Mining Institute, and in the opinion of the Committee of the Trade, that it is highly desirable to establish a College for the Advancement of Practical Mining and Manufacturing Science at Newcastle, a locality so well adapted for that purpose, and strongly recommend the Trade to support the same: and the meeting is further of opinion that the Lessors of Mines

and the Mining Interests generally of this and other portions of the Kingdom, as well as the Government, should be applied to for support to such Institution, the object of which appears to the meeting one of not merely local but of national importance, bearing as it does upon increased skill and economy in production, and also upon the due security of life and property.

The CHAIRMAN briefly added, that there could be but one opinion in reference to the very flattering report and resolution just read. With respect to the recommendation that the Institute should proceed to canvas the rest of the trade in other districts, that was a subject which he considered should be left entirely in the hands of the Council, in order that they might take such steps as they deemed necessary to prosecute the object. He understood that the question will be brought before the whole trade in London in the month of March next.

A brief conversation then ensued in which the following gentlemen took part:—Mr. ATKINSON, Mr. HALL, Mr. LONGRIDGE, Mr. M. DUNN, and Mr. BARKAS. The purport of their remarks were all in favour of the College: also, of the necessity of moving forward cautiously and securely, and of the further progress of the scheme being left in the hands of the Council of the Institute. Ultimately the following resolution was agreed to—

RESOLVED,—That the Council be requested to take such further steps in the prosecution of the plan for the establishment in this town of a College of Mining Science as they may deem requisite, the Council laying before a subsequent meeting of the Institute a report of what has been done.

The SECRETARY next read a letter from Mr. Boyd, the treasurer, relative to the difficulty he had in getting the subscriptions in from the different collieries; but after some conversation on the subject the Secretary was instructed to write to Mr. Boyd, stating that he must take the best means possible to accomplish his purpose.

A letter was read from Mr. Marley, of Bishopwearmouth, relative to the safety cage of Messrs. Grant and Co., which gave rise to some discussion as to its relative merits.

Mr. HALL intimated that he had taken some trouble to introduce Grant's cage with its grips to the notice of the members of the Institute, and got the model in the room for inspection, showing the mode of putting on the grips to the cage. Several gentlemen, however, seemed to think that the risk incurred with the grips would be greater than the benefit they were likely to confer on the workmen, and especially in regard to deep pits, where great speed was required. It was contended that the

grips or guides in the shafts could not be kept constantly in order. Mr. Thomas Wood, of Thornley, and others, had tried them. They found them similar to Fourdrinier's plan of grips; and they thought that if Grant's were generally in use it was possible that the loss of life might be more with them than without.

A discussion then ensued, some contending that their use were questionable, while other members stated that they knew instances in which it had been instrumental in saving the lives of workmen. Mr. ANDERSON narrated one or two facts illustrative of their safety, and Mr. DUNN, government inspector, adverted to an inquest or two at which he was present, where parties had been killed by falling down the shaft by some accident occurring to the rope, and stated it as his opinion that had Grant's cage been at the pits in question the men's lives might have been saved.

Mr. LONGRIDGE deprecated the propriety of arriving at any definite opinion on the subject, as it was irregular; beside, it would be very injudicious for the Institute, as a body, to give any opinion as to the merits of the cage. Individual members might give an opinion regarding it, but the Institute ought not to commit itself in any such way.

Several other members coincided with Mr. Longridge, and as Mr. Dunn had paid some attention to the subject, it was suggested that he would, perhaps, hereafter draw up a document and submit it to the Institute for discussion.

Mr. DUNN having assented to such a course, the following motion was then passed in reference to the letter of Mr. Marley :—

That the Secretary be instructed to inform Mr. Marley that the members of the Institute must decline giving, as a body, any opinion on the merits of Messrs. Grant's cage, but are willing, if the subject be brought forward before them to discuss it, to elicit the opinions of individuals.

The SECRETARY then announced that the next subject for discussion was the paper of Mr. Reid, "On Practice with Gas at Blowers."

Mr. HALL had no objection to such a course, but he submitted that the discussion on his paper should be resumed, as Mr. Dunn said that he thought the subject had not been sufficiently discussed. Up to the present he had every reason to believe that his paper, together with the map of the coal-field, were correct, as no one had yet pointed out any errors in them.

The CHAIRMAN thought if such a course was in order, the members might as well proceed with Mr. Hall's paper, so that it might be finally

disposed of. For himself he thought the paper had been fully discussed; but nevertheless, if any one had anything to add, the meeting would be glad to hear him.

Mr. LONGRIDGE thought it very desirable for any one to point out if they could, any error in Mr. Hall's paper, as the value of it depended upon its accuracy.

The CHAIRMAN after a pause, finding that no one was inclined to say anything, submitted the propriety of adjourning the discussion on Mr. Reid's valuable paper, inasmuch as both the President and Mr. Taylor, as well as other members, were absent.

This having been agreed to, the meeting broke up.

NORTH OF ENGLAND INSTITUTE

OF

MINING ENGINEERS.

MONTHLY MEETING, THURSDAY, MARCH 1, 1855, IN THE ROOMS OF THE INSTITUTE, WESTGATE STREET, NEWCASTLE-UPON-TYNE.

NICHOLAS WOOD, ESQ., PRESIDENT OF THE INSTITUTE, IN THE CHAIR.

The SECRETARY having read the minutes of the proceedings of the Council, the following gentleman was elected a member:—Mr. J. L. Simpson, Blaydon Burn.

The PRESIDENT then informed the meeting that he had received a copy of Mr. Greenwell's work on Mine Engineering, as a present to the Institute. The work was most excellently got up, and the least they could do in return was to pass a vote of thanks to that gentleman. He, therefore, begged to move a vote of thanks to Mr. Greenwell.

Carried by acclamation.

The PRESIDENT then intimated that the next business before the meeting was to discuss the merits of papers that were in arrears, and in particular that of Mr. Hall's, Mr. Longridge's, and Mr. Reid's. With respect to the latter paper it had long been before them, and he supposed the members would be quite prepared to make some observations upon it, and with that object he should be glad to hear any observations thereon. He thought there were some things in Mr. Reid's paper which were very useful, and some which required consideration. In the first place he asked Mr. Reid if he had anything further to explain?

Mr. Reid.—No; the paper was wholly composed of facts, and therefore it contained little or no theoretical matter.

Mr. Atkinson observed that as there appeared one point in Mr. Reid's paper rather remarkable, he begged to call attention to it, as he was inclined to think that Mr. Reid was in error. The point he referred to was at page 38, where some particulars were given relative to the effects of a blower of gas. The conclusion arrived at was that the pressure of the gas was 67½ lbs. per square inch, or 4½ atmospheres. This amount of elasticity, he considered, was based upon erroneous grounds. Mr. Reid, in his paper, assumed that in two air-ways opposed to each other, the pressure, to be in equilibrium must be greater in the one area than the other, in the inverse ratio of their areas; but the only way, in his (Mr. A.'s) opinion, to arrive at the real pressure of gas exerted, was to ascertain the velocity with which it issued from the gullet, and to calculate the force required to produce such velocity. Mr. Atkinson then explained his views on the subject as follows:—

"It is presumed that the pressure per unit of surface exerted by the gas on an area of 12 feet, opening into an air-way with an area of 54 feet, must have been such as that the product found by multiplying the pressure per unit of surface exerted by the gas, into the area through which it passed into the air-way, must have represented a gross pressure on the entire area at least equal to the pressure of the atmosphere in the air-way multiplied into the area of the air-way itself, because the pressure of the gas overcame that of the atmosphere.

"The above conclusion is not in accordance with the laws of nature, it being a fact that the slightest excess of pressure per unit of surface exerted by the gas over that of the air coming towards it, would suffice to enable it to "back" or penetrate into and mix with the air.

"What is termed the hydrostatic paradox, or what may here be termed the pneumatic paradox, is brought into notice:—the gross pressure distributed over the entire surface is not the criterion whereby to determine the pressures, all that requires consideration is the pressure exerted on each unit of surface by the gas and the air respectively, whichever of them exerted the greatest pressure per unit of surface would prevail against the other, quite independent of the areas over which they operated; no data appears to be given in this case, whereby to decide to what amount the pressure per unit of surface, exerted by the gas, exceeded that exerted by the air.

"At page 41 a similar error is fallen into, and because it is presumed that gas escaped out of a gullet of $1\frac{1}{4}$ feet area, at such a pressure as to back the air in air-ways of 36 feet area, besides filling a staple in the return having 40 feet area, the mistaken conclusion is arrived at that the pressure per unit of surface exerted by the gas must have been $\frac{76}{11} = 60{\cdot}8$ times as great as that exerted by the atmosphere, giving thus the incredible pressure of 912lbs. on the square inch, as being due to the escaping gas.

"Although the data furnished in the latter case are not such as to enable us to determine the pressure at which the gas might exist in any reservoir from which it might escape, if it happened to have to force its way through long and narrow channels before reaching the gullet by which it escaped, yet they are such as to enable us to determine with some degree of certainty the actual pressure at which the gas really escaped from the gullet.

"The velocity with which the gas escaped, according to the data furnished in the paper, is 37,634·4 feet per minute, and this velocity would require a head of 6115·5 feet of gas column to generate it; see [10], in my paper on ventilation, page 78.

"The density of the inflammable gases in coal mines in this vicinity may be taken to be ·63, that of air at the same temperature and density being 1, and at an average temperature and under atmospheric pressure will therefore weigh about ·047lbs. per cubic foot, and hence the pressure due to the velocity of the escape of the gas from the gullet would be $6115{\cdot}5 \times {\cdot}047 = 287{\cdot}428$lbs. per foot, or nearly 2lbs. per inch above the pressure of the atmosphere or medium into which it escaped, so that the conclusion as to its being $912 - 15 = 897$lbs. per square inch above that pressure is evidently very much over-rated."

Mr. Greenwell supposed that Mr. Atkinson, in that calculation, did not include the pressure necessary to overcome the friction of the gas passing along and through the gullet?

Mr. Atkinson—That he could not ascertain, as the gas probably existed at a great distance from the point of issue; but if not, they must know that according to the facts related they had the effect of the pressure at the orifice of the gullet.

Mr. Greenwell—Perhaps Mr. Atkinson assumed it had issued into a vacuum?

Mr. Atkinson—No; he calculated the gas as issuing into the atmosphere.

The PRESIDENT—What has been pointed out by Mr. Atkinson was just the same as he mentioned to Mr. Reid previously; for it did appear to him (the President) that the mode of calculation adopted was not correct. In page 41, Mr. Reid gave the area at the aperture where the gas issued at 180 square inches, and after stating the pressure at the time the gas was passing, he further says at page 42, that

"Applying this quantity to the gullet area of the blower, and assuming the time of its exuding at one minute, we have the apparent velocity of gas escaping per square inch of surface in that time equal to 261·35 feet, or at the amazing rate of 37,634·40 per square foot of area."

This mode (continued the President) of calculation was incorrect. He thought the correct mode was to ascertain the force required to produce the velocity, which was stated, through an aperture of an area equal to that through which the gas issued. Mr. Reid seemed to have calculated the number of atmospheres which was required to check the current of air passing along the drift, and it was stated that the gas forced the current of air in an opposite direction: this would, no doubt, require a considerable force; and the real question certainly was—What was the force required to do that? as this would be an element in the calculation of the force required to cause the gas to issue from the gullet or blower at a definite velocity.

Mr. GREENWELL—Besides, another point to be considered, was the increased pressure due to the length of the orifice or channel through which the gas passed. It was assumed that the gas merely passed through a thin orifice into the atmosphere, whereas the blower passes through crevices of an unknown length.

Mr. ATKINSON included all that in his first statement. There was no other data to determine the force which existed at the mouth of the orifice except the velocity with which the gas issued.

Mr. BARKAS observed that in every case of blower coming suddenly off, if with great force, he always found it to back the current of air, which he supposed arose from the different densities of the gas and the atmospheric air. He did not know whether gas would have the same effect as if it was atmospheric air coming off with the same velocity, as there was the effect of the difficulty of the gas and the atmospheric air to mix together, he thought the mode of calculation adopted by Mr. Atkinson was the correct way of getting at the velocity. Taking all the elements into consideration, the question required considerable thought, as they

would find that there was a great deal in the manner in which the gas was evolved.

Several other brief remarks were made by one or two members of similar import to the foregoing,—after which

Mr. Reid briefly replied in general terms to the remarks of Mr. Atkinson, by stating that he was not then prepared to go fully into the point at issue without considering the subject more carefully. One thing he would admit, and that was that his calculations on the actual pressure of the gas were made from simple facts,—he did not pledge himself to the absolute correctness of the figures given, but he must say that so far as he could judge at present, he could not agree with Mr. Atkinson that the pressure which he assumed could produce the effect which was observed. As regarded gas issuing into free space that was entirely a different thing. He was not then prepared to go further into the subject, but would take it up some other time.

Mr. Barkas stated he had a case at Waldridge Colliery, and which he believed was not a very unfrequent one, where the force of gas raised the thill or pavement of the mine about a foot or upwards of solid rock or shale.

The President suggested that the same plan which was observed at the Civil Engineers' proceedings might be adopted by that Institute, which was that at each succeeding meeting the minutes of every previous meeting were read over, so that if any gentleman had any further observations to make on any given subject he could do so, and time was given for consideration. If such a scheme was adopted they might come at the end of the succeeding month prepared for the subject in discussion. Their object was only to elicit the opinions of members, and to arrive at sound and correct conclusions upon the questions at issue. Mr. Atkinson contended that Mr. Reid should measure his force by the velocity at which the gas issued from the aperture. Mr. Atkinson's remarks, however, would be printed, so that by the next meeting the discussion could be resumed.

The subject then dropped, with the understanding that it be hereafter resumed.

The President next called attention to the paper of Mr. H. G. Longridge, and stated that for himself he thought it one of great importance, as it referred to the probable supply of coal to the fleet now in the Black Sea, and to steam vessels hereafter employed in the trade of that part of Turkey and the Danube, and therefore he should be glad to

receive any further information on the subject. It was stated in the newspapers that the mines alluded to by Mr. Longridge were in operation, under the superintendence of Mr. Berkley.

Mr. LONGRIDGE in reply said, that his paper contained a statement of facts: that he had no further particulars to communicate, but would be most glad to answer any questions. With regard to any further information, that would be found in the papers published before Parliament.

The PRESIDENT—But that did not contain more information than they had in his paper.

Mr. LONGRIDGE—He knew that directions had been given to open out the second valley alluded to in his paper, from whence the Government were going to draw a great part of the supplies.

The PRESIDENT understood an arrangement had been made with the Turkish Government, and that it was intended to supply Her Majesty's fleets from these collieries.

Mr. LONGRIDGE—Yes, it was computed they would be able to get upwards of 35,000 tons per annum: but before they could do so, they would require a great number of labourers.

The PRESIDENT—Did the papers before Parliament state the specific quality of the coal?

Mr. LONGRIDGE—Not very particularly; but experiments had been made on the spot at the request of the Government, and the report to the Admiralty was to the effect that the quality of the coal was suitable for steam purposes, but it was not so good in quality as the coal in England.

Mr. HALL thought it was found that the coal got harder as it approached seaward.

The PRESIDENT then remarked that, in a commercial point of view, coal obtained at the Black Sea was of great importance to this country, as, if coal could be got there at a cheap rate, it could not fail to facilitate commerce between this country and Turkey. What really wanted was, cheaper coal at such distant places, which would tend to assist rather than operate against the coal trade of this country.

The meeting then broke up.

NORTH OF ENGLAND INSTITUTE

OF

MINING ENGINEERS.

MONTHLY MEETING, THURSDAY, APRIL 5, 1855, IN THE ROOMS OF THE INSTITUTE, WESTGATE STREET, NEWCASTLE-UPON-TYNE.

NICHOLAS WOOD, ESQ., PRESIDENT OF THE INSTITUTE, IN THE CHAIR.

The minutes of the Council having been read by the SECRETARY,

The PRESIDENT laid before the meeting a section of the coal and ironstone measures of the county of Lanarkshire, in Scotlond, presented to the Institute by Mr. Moor, of Glasgow.

It was resolved that the thanks of the meeting be given to Mr. Moor, and that the President be requested to convey the same to that gentleman.

A letter was read, addressed to the Secretary, by Mr. John Weale, the publisher, of High Holborn, London, stating that the annual expense of advertising the Transactions of the Society, in certain publications, of which he proposed to send a list, would average ten pounds or thereabouts.

It was resolved, that Mr. Weale be empowered to expend the above sum annually on advertisements, and that he be requested to transmit the list of publications promised.

It having been suggested that the hour of two o'clock was too late for holding the general meetings of the Society, and that one o'clock would probably be a more convenient hour; it was agreed that the notice of the

members be directed to this alteration, with a request that they would consider the same, and come prepared to the anniversary meeting to arrive at some determination thereon.

The PRESIDENT then read to the meeting a letter addressed to him by Mr. P. S. Reid, on the objections brought against some of his calculations of the force by which explosive gasses issue from fissures in coal mines, as given in his Paper to the Institute in November last; and suggesting, as he was unable to attend the meeting from illness, that the further discussion should be postponed until he could be present.

It was arranged that the further discussion of the Paper be deferred until the next meeting of the Society, and that Mr. Reid and the members be apprised thereof accordingly.

Agreeably to the suggestion of the President at the last meeting, that Mr. Atkinson should draw out, for the consideration of the Institute, some practical deductions from his elaborate Paper on the "Theory of the Ventilation of Coal Mines," to further the discussion on that Paper; Mr. Atkinson presented a paper containing the different heads under which he proposed the discussion should be conducted—such heads presenting practical deductions from the theoretical disquisitions in his Paper.

A discussion then took place as to the best mode of proceeding on such an important subject, and it was ultimately arranged that Mr. Atkinson's paper containing the heads for discussion be laid upon the table of the Institute, that the attention of the members be called by an early circular to the fact, and that the members be informed that the discussion will take place at the next meeting in May, and be continued until the subject be fully discussed.

The PRESIDENT observed that, as Mr. Atkinson's Paper contained the entire theoretical exposition of the ventilation of coal mines, than which nothing could be of more interest to the society; and as they were essentially a practical body, it was advisable, indeed if not absolutely necessary, that, in the first place, the theoretical conclusions should be thoroughly investigated; and next, and most important, that the application of that theory to practice should likewise be carefully and fully considered, so that they might elicit some useful practical conclusions on the subject; and as the subject was of such importance he trusted they would have a full meeting, that as much as possible of the practical knowledge of the Institute should be brought to bear upon the discussion.

The following members who had been proposed at the last monthly

meeting were ballotted for, and unanimously elected, viz.:—Henry William F. Bolckow, Middlesbro', near Stockton-on-Tees; John Vaughan, of Middlesbro', near Stockton-on-Tees; John Straker, of North Shields.

The PRESIDENT then proceeded to read his Paper on the "Conveyance of Coals Underground in Coal Mines," after which the meeting adjourned to the first Thursday in May, at two o'clock.

ON THE

CONVEYANCE OF COALS

UNDERGROUND IN

COAL MINES.

BY NICHOLAS WOOD, ESQ., C.E.,

PRESIDENT OF THE INSTITUTE OF MINING ENGINEERS.

The subject of the conveyance of coal underground in coal mines from its separation in the mine to the bottom of the pits is of great importance to the coal trade. The increased cost, above that of the conveyance of coals, and other minerals, by railways on the surface, demand the attention of every one connected with the management of mines, with a view of ascertaining if such cost can in any manner be lessened.

In the year 1825, I published a practical work on the subject of "The Establishment and Economy of Railways" on the Surface, which, subsequently, went through another edition, published in 1831, and the great progress which railways, and the motive power employed upon them, since that period has undergone, raises a very important question whether such improvements have been adopted in the conveyance of coals underground, and whether sufficient attention has been paid to the subject or not.

There is, however, a wide difference in the circumstances of the two cases—surface railways can be levelled and made of uniform inclination at comparatively small cost to that by which they can be made underground—the latter is, in fact, entirely tunnelling—more even than that, as in the first formation of a road underground the coal is seldom of sufficient height to allow of horses to travel, or for the use of the requisite carriages: and, consequently, the dimensions of the excavation must be

enlarged even before any attempt is made to make the road of an uniform inclination, or to adapt it to any particular description of motive power.

And when it becomes necessary to level up depressions and to take off undulations, then it is very expensive tunnelling in solid rock; sometimes excessively hard and extremely expensive, but always presenting very much greater cost than a similar process on the surface.

And it must also be borne in mind, that there is this difference between making roads underground and on the surface—that in the latter case, perfect levellings can previously be obtained of all the undulations of the surface, and this before any expenditure at all is incurred, and a line of railway thus fixed upon or adopted, which can be formed at the least possible cost. In underground mining or tunnelling, it is all in the dark, we can only guess at the undulations before us; and, therefore, when a certain direction or course is assumed, and which is expected to produce the requisite degree of inclination, the undulations in the strata, or breaks up and down by dykes, often thwart all our calculations. The perfection of a railway is, we presume, that between two points it should be as level and as straight as possible, if the amount and weight of the traffic is the same in both directions; or, if there is a preponderance of traffic in either direction, then that the inclination should be such as to present the same resistance to the motive power in both directions.

In mining engineering, if the ruling principle laid down be that the road should have a certain inclination, either that it should be just water-level, or such an inclination as that the water will just flow from the workings to the pumping shaft, or that it should be such an inclination as that the resistance to the load should be equal in both directions; then if there are any undulations in the regularity of the strata, or bed of coal—[and in every mine such undulations are very frequent, and sometimes very considerable]—then it will be found that to preserve the requisite levels the road, instead of being straight, assumes the most tortuous shape; and in cases where the roads are numerous, and where the levels or roads of two or three beds of coal are laid down upon the same map, they assume very much the tortuous appearances of the gyrations of the animalcula exhibited in an oxyhydra lens.

The formation of the roads underground approach more nearly to that of the formation of a canal through a hilly country, with this difference, that in the formation of a canal on the surface, the engineer can make surveys to regulate and guide the line he may take in its formation, whereas, a mining engineer has to form his canal without being able ever

to see beyond that part of the road in which he is immediately engaged in forming.

The beds of coal, also, are generally from three to four, or five feet in thickness, probably the average about four feet; and the height required for horses or machinery about six feet when finished. The rock above or below the bed of coal is generally extremely expensive to excavate, and hence any extra quantity of rock to be taken up or blasted down, beyond that which is absolutely necessary, is very expensive. Vertically, the whole space to operate on is about four feet.

The draining of a mine is, likewise, generally an expensive operation. When, therefore, a pit is sunk, and the pumping apparatus attached, it becomes of great importance that as large an extent of mine should be drained as possible. The first operation, therefore, generally is, to push away right and left, what are called the water-levels of the colliery, viz :— drifts, adits, or levels, with such an inclination only as that the water will just run towards the bottom of the pit, and these are pushed or extended across the whole extent of the royalty, from one extremity to the other, in the water-level line of the strata or bed of coal, by which all the coal on the rise side of the water levels are drained.

These, as before explained, are generally extremely tortuous, if the bed of coal at all undulates. For the purpose of merely water-levels, this is not of very much consequence; but these levels being at the lowest point at which the seam is opened out, they are very often made the main roads also, whereby the coals are brought out to the bottom of the pit.

In the early period of coal mining, and up to a comparatively recent period in the best managed districts, and, indeed, in the present day in those districts where the stimulus given by the improvements of surface railways has not reached, it is found that almost universally the levels which drain the mine are the horse-roads by which the coals are brought out from the workings to the bottom of the shaft. The coals from the rise parts of the mine being brought down to those levels or roads.

Where the mines are extensive, and where the expense of lifting the water is costly, or where they are drained by day levels, the greatest care is taken in making those levels as flat as possible, barely, or just sufficient inclination for the water to find its way to the pumping shaft or adit, and the horse-road being either formed on the water-level, or on a road driven parallel thereto; this circumstance operates very materially in determining the description of road by which the coals are brought out, and the kind of motive power to be employed thereon.

In the early period of coal mining likewise, and prior to the introduction of mechanical machinery to pump the water, the coal was drained by adits into the sides of the hills—there it became of great importance to adhere to the water level of the strata in draining the mine, and when, even at a later period, machinery was introduced to drain the mine, this was only able to be performed to a certain extent,—and to the extent to which this drainage could be performed it became of equal importance that, as the miners termed it, "no level should be lost," but that the levels should be driven strictly water level; and even at a late, and up to the present period, the same rule holds good, viz:—that the levels should be driven strictly water level, hence the coals having to be brought out towards the entrance to the mine on such a gradient, and the load being consequently all in one direction, the motive power is not equally balanced, but greater in the direction of the load than with the empty carriages. Thus, the main-roads for bringing out the coals to the bottom of the pits or adits, may be said to be the water-levels of the mine, the cross-roads bringing the coals from the rise to those roads, and when the stratification of the mine is sufficiently inclined, or the beds lay at an adequate inclination, then the coals are brought down to the main-levels by self-acting planes, and so to the bottom of the pits.

The earliest attempt, therefore, to work coals no doubt began in digging it out where exposed to the surface, or where the beds cropped out to the surface, by adits or levels driven in the direction of the beds water level, the same level or adit answering the double purpose of drainage and a road to bring the coals out.

We have no records of how or in what manner the coals were brought out to the surface before the introduction of railways. We know that even within the last thirty years coals were carried out to the surface in Scotland by women who were called "bearers," and who carried out very heavy weights of coal in panniers, much the same as the fish is carried by the fisherwomen, and where pits were necessary, steps were placed within the area of the shaft which the women ascended with their load of coals.

It is probable also that barrows were at one period extensively used for conveying the coals to the mouth of the adit, or to the bottom of the pits, and that where the floor of the mine was soft, planks were laid down whereon to wheel the barrows; and likewise, before the introduction of railways, sledges were used in which the baskets or corves were placed which contained the coals. In this case, also, where the floor of the mine was soft planks were used. These latter roads were likewise called "bar-

row-ways," which would indicate they were the same description of roads, and used for the same purpose as the roads where barrows were used. To a comparatively recent date sledges were used in the pits on the main roads, and likewise on the surface at the top of the pits to convey the coals from the mouth of the pit to the screens, or to the waggons used to convey the coals to the shipping places.

In those districts where early mining has been practised we find the pits very shallow and very numerous. The earliest working having been by adit as before named, and the powers of drainage being at those periods very inefficient, the pits would necessarily be very shallow, limited to the power of raising the water of the mine. And when the mode of conveyance underground was confined to barrows, numerous pits would be requisite to be sunk to supply the deficient and expensive system of conveyance. As the system of conveyance was improved, even by the introduction of sledges, the necessity for sinking pits would be less; but even up almost to the end of the last century, the number of pits sunk was very numerous; although, perhaps, the question of ventilation may, in some cases, have regulated the frequency of sinking.

Horses were, no doubt, used for a long period in the shallow pits for drawing the coals to bank by gins; but the depth to which they could raise the coals was, though limited, very much beyond that of manual labour.

The next process was, probably, the use of water-wheels, wherever such a power could be applied; and hence we find that water-wheels were used at and up to a not very distant period, both for the drainage of the mine and for drawing the coals to bank. And such appears to have been the reluctance to part with an old friend, that long after the introduction of the steam engine, the latter was, in many cases, employed to pump the water up to the requisite height, to be afterwards used in working the water-wheel.

In some of the mountainous districts of Wales, water-wheels are indeed still used; and the use of water has been carried to a much greater extent than it can be carried in this manner, especially in South Wales, by the use of what are called "Balance Pits;" where water is run into a bucket attached to a rope or chain passing over a pulley at the top of the pit, of a greater weight than that of the coals, or weight to be drawn up the shaft, and which is attached to the other end of the rope or chain. The water descending thus draws the coals up the pit; the water is then emptied at the

bottom, the loaded tub of coals placed over it, and they are then drawn up the pit by another and similar process. The water generally runs out to the surface by adits; but in some cases it has to be lifted either by water-wheels or by steam engines. Coals are thus drawn to bank up pits of a depth of 60 to 80 fathoms.

These observations though not, perhaps, strictly applicable to the subject of this paper, are not entirely irrelevant thereto, as the powers of raising the coal to the surface, and, consequently, the number of openings in a given area, modify and determine, to a considerable extent, the means and the mode applied to convey the coals from the workings to such openings. Hence we find in the early stages of the working of coal mines the roads were made from the adits, and from pit to pit, in the water-level line of the coal, draining and cutting off a strip of coal nearest the surface at the least possible cost and labour. Successive strips were then drained or worked more and more towards the dip of the mine, or at greater depth from the surface, as longer and more expensive adits were driven, or as successive improvements advanced, and more power was applied to lift the water and to raise the coal to bank.

Hence it was then the system to commence the winning and working of the mine at the extreme rise part of the coal-field, with successive drainage, and working deeper and deeper, as more power was obtained. This is most clearly exemplified in the valleys and in the hilly and mountainous coal-fields of Great Britain, and especially in the hills of the extensive coal-fields of South Wales. The successive deeper levels, being almost an index of the development of the continuous advancement in science and in the improvements of machinery.

Now, when we may almost be said to have attained such a degree of perfection in machinery and in engine power to almost, if not quite, command the drainage of the deepest part of any of our coal basins, [as the coal measures being the uppermost beds of the series of rocks on which they repose, the coal does not extend to a very great depth from the surface in the coal fields of Great Britain], and when we can, consequently, place the draining pit, or drawing shaft, in the deepest, or in any other part of any coal field or royalty; we are, consequently, enabled so far as the number of openings to which the coal is to be conveyed underground extends, to place such openings at that point of the coal-field to which the coal can most advantageously be conveyed.

This very circumstance, as the natural effect of such a command of

power involves, however, has been the cause of much deeper openings being made,—more expensive, and, consequently, less in number; and, therefore, requires that the coals should be conveyed a much greater distance underground than heretofore.

While, therefore, in the early stages of coal mining, the openings were never more than a hundred, or two or three hundred yards apart, increasing in distance as improvements of winning, draining, and conveyance of the minerals advanced; and even up to within the last half-century, the pits were never more than half a mile or so distant. And though the ventilation of the mine in some degree regulated the distance, like the other improvements in the science and practice of mining, ventilation was improved in the same ratio and kept pace with the other requisites of more extensive mining operations. Now, at the present time, the distance of the pits or openings from each other in the deep mines, are as many miles as they were hundred yards apart in the early period of coal mining. And we consequently see the necessity and importance of the consideration of the means and economy of conveyance of the coals underground in the present extensive system of mining operations.

Having thus given a general outline of the progress and successive increased means of the conveyance of the coals underground, and having pointed out the difficulties attendant on underground operations as contrasted with similar operations on the surface, I shall now enter into the detail of these different modes practised during the successive periods up to the present time. I shall then investigate the powers of each mode, or the motive power employed, which I shall illustrate, as much as possible, by experiments and diagrams; and I shall then endeavour to produce some practical results from the enquiry.

It is unnecessary to enter into the minutia or detail of the conveyance of coals by barrows, or by sledges, or even by the more repugnant mode of carrying the coals on the backs of ladies. All these modes are only matters of history, except where the seams are much inclined, and where sledges are used to convey the coals from the face of the workings to the main roads, which I shall now shortly describe.

On the Continent, viz:—in France, Belgium, and Prussia, where the beds of coal are much inclined to the surface, and where the inclination is such that the coals will not slide down the floor of the mine into the main roads, and in some parts of England and Wales also, in similar situations, sledges are used to convey the coals from the face of

the workings to the main roads, and the coals are either packed upon the sledges, and by them conveyed to the bottom of the pit, or emptied into the tubs by which the coals are conveyed along the main roads to the bottom of the pit or to the mouth of the levels.

In these cases the main roads are formed along the water-level course of the coal, and at short distances from each other in the rise of the beds; between which the coal is generally taken away by the long wall system, in one process, the entire width between the two roads; or it may be worked by the pillar and wall system, the pillars being generally taken away and brought to the same headway as that by which the whole coal is worked, and as the work proceeds to the rise the coals are brought to the lower levels by self-acting inclined planes. Boys are generally employed for this purpose.

Sledges, as before stated, were also used very extensively in the main roads in the more flat mines of England and Wales to carry the coals, from where worked in the face, to the pit, which were drawn by ponies; and when the beds of coal were thick horses were used. These sledges were dragged along the bottom or thill of the mine where it was hard, but where it was soft deals or planks were laid down, or penning, composed of narrow pieces of wood laid across the roads, and these were, as before stated, called in the districts of Northumberland and Durham "barrow-ways."

In these cases one pony, or one horse, was always employed to drag one basket or corf of coals at a time, and, consequently, as may be presumed, and indeed as was the fact, the expense was considerable; hence the necessity, when the beds of coals were not at a great depth from the surface, of having frequent openings or pits, by which the coals could be drawn to the surface.

The next step was the employment of wheel carriages, which ran upon timber roads, or railways formed of timber. The carriages had wheels similar to our tram wheels, running upon the flat wooden rails, with a ledge on one side, (similar to the cast iron plate rails), to keep the wheels upon the road. But cylindrical wheels, running on wooden roads, similar to the old ledge wooden railways, were likewise used. The wheels were originally of wood with wooden flanches, but subsequently a flat bar or hoop of iron formed the periphery of the wheel, with a plate of iron to act as the flanch of the wheel.

These wooden rails and railways, have, like similar railways on the sur-

face, now given way to cast or malleable iron railways, either the common tram road or the edge rail; and to carriages with wheels of either cast or wrought iron, suitable for each description of railway.

For a long period, or rather down to a very recent period, tram roads with the tram wheel were universally used in this district, but they have now been, if not quite, almost universally superseded by the edge or round top rail. In some districts of England, Wales, and Scotland, however, the tram road is still in use, a prejudice still existing against the use of the edge rail. In most of the iron works in Wales and Scotland, the underground railways are tram roads, with wheels loose on the axle, and constructed so that when a wheel breaks it can easily be replaced.

Up to a recent period also, in the Northumberland and Durham districts, the coals were drawn to bank by baskets or corves. These were placed upon the sledge (when sledges were used), and brought out to the bottom of the pit, were then attached to the rope, and drawn to bank, leaving the sledge at the bottom of the pit. The corf, or basket, was then placed upon another sledge at bank, and so conveyed to the screens or wagons, and the coals emptied out, the empty corf, or basket, having, in the meantime, been again sent down the pit.

In many of the pits in the Midland districts, in Scotland and in Wales, the coals, especially where they are hard and large, are placed on and and packed upon the sledges, or trams, or waggons with iron rings, and are so drawn up the pit, both trams and coals. In these cases, however, it is necessary to have guides in the shafts to prevent the trams, or carriages, from striking the sides of the shaft, and from striking each other in passing at meeting in the shaft. Great weights are generally drawn at a time, and the motion or velocity in drawing the coals to bank is extremely slow, the principle being to bring to bank large weights at a slow speed.

The contrary is the practice in the North of England, the pits being generally of a much greater depth. The principle is to draw comparatively smaller weights up the shaft but at great rates of speed. And though this practice is more particularly applicable, perhaps, to a comparatively recent period, it is now customary to draw to bank, at one of the pits in the North of England, as many coals as are drawn to bank at two or three of the pits in the Midland Districts or in Scotland and Wales.

It may, however, be remarked, that in the latter localities, the workings

have not yet penetrated to such great depths as the workings in the Newcastle District have done, the necessity has not, therefore, yet arisen, as a measure of economy in the latter case, to have fewer pits and to bring larger quantities of coals to bank at each pit. Still, however, when the greater expense of conveying coals underground as compared with that of the conveyance of coals on the surface is considered, it will, in some cases, be found to be more economical to have more pits with a less distance to convey the coals underground, than fewer pits and a more extended conveyance underground.

It was, for a long time, deemed inconsistent with the principle and economy of drawing coals at a rapid rate up the shafts in the North of England, to adopt the system of the Midland Districts of drawing the coals along with the tubs or carriages up the pits, especially when combined with greater comparative weights, and with the system of guides or slides. Ultimately, however, the mode of drawing both the coals and carriages to bank was adopted in this district, and with it, of course, the system of slides in the shafts. And such has been the rapidity of conversion to this system, that, at this time, I do not believe there is a single colliery where this system is not adopted, and the old plan of drawing the coals to bank in baskets or corves is not abandoned.

While baskets or corves were used the system of conveyance of the coals underground was to employ small carriages called *trams*, usually running on plate rails, but sometimes on round or edge rails. The coals were thus brought out from the face of the workings to the main roads by boys which were called "putters," (and here it may be remarked, that even after the tram or plate, and the edge railways were introduced, these roads were still designated "barrow-ways,") the corves were then lifted by small cranes from the trams and placed upon larger carriages which were called "*rolleys*," the roads being called "rolley-ways," by which they were conveyed to the bottom of the shaft.

In some cases, even since the system of drawing the tubs as well as the coals to bank has been adopted, the trams or tubs are placed upon the large carriages or *rolleys*, which are then more generally called "*wagons*," (especially where edge rails are used,) and so conveyed to the bottom of the pit, this system has now, however, almost universally given way to the plan of using the same *tram* or carriage to convey the coals from the face of the workings to the bottom of the pit, and these are mostly called "*tubs*."

Figs. 1 *and* 2, *Plate* 1, shews the tubs now most generally used, there are, of course, a great variety of dimensions or forms used, either with the wheels outside of the body of the tub or underneath, with different sized wheels, according as the bed of coal is of more or less thickness.

It will be seen hereafter that a great advantage exists in the employment of wheels of large diameter, and as the wheels of the tubs which are used must, of necessity, travel into the workings, their size are regulated by the height of the seam. They are generally only from 8 to 12 inches in diameter. On the main roads, where horses are used, or where horses have to pass along, there is necessarily a greater height, so that wheels of a larger diameter could be used, and consequently the friction would be very much reduced, so much so that in the cases of the tubs being placed upon wagons as previously described, the diminution is almost, if not quite equal to the useless weight of the trams carried upon the larger wagons. But the trouble, delay, and expense of transferring the smaller to the larger carriages, has been considered to so far outbalance any advantage obtained by the diminution of friction, that the smaller wagons or tubs, though the length of the roads are sometimes equal to two miles, are used in preference to the larger wagons.

Considering, that no great practical result would be obtained by enquiring into the resistance or friction, or the effect on the transit of coals of those systems which have been abandoned, or which are only partially in use, I have confined my experiments to the carriages or tubs almost universally used in the collieries of the Counties of Durham and Northumberland, though I shall endeavour to compare their effect with some of the modes not yet abandoned in some of the other districts of the kingdom.

FRICTION OF CARRIAGES.

It is scarcely necessary to state that in all carriages moved on railways, with wheels, the friction of such carriages is composed of two descriptions of resistance, viz.: that which is due to the friction of the attrition on the axles, and that which arises from the resistance of the periphery of the wheel upon the rail.

In my work on railroads I gave a great many experiments to ascertain not only the entire resistance of carriages moved on railroads, but also the amount of each of those two descriptions of resistances; and from

these experiments, as well as from the well known laws of mechanics, I have deduced some practical conclusions.

Rapid strides have since been made in the improvments of carriages upon railways,—but the experiments thus alluded to having been made on the railroads then in existence, and which were almost exclusively private colliery railways,—and as the carriages on which these experiments were made more nearly assimilates to those of the underground carriages now employed in the collieries, they will be probably more useful as illustrative of the resistance of such carriages than experiments made upon the more improved carriages of the present day upon public railways.

The result of the experiments above alluded to, and made on the wagons used on the private railways, when my work was published, was, that the friction of such wagons was about the $\frac{1}{200}$ part of the weight, the rolling or resistance of the wheels on the rails being about the $\frac{1}{1000}$ part of the weight, and the conclusion derived from the experiments then made was—

That, in practice, we may consider the friction of carriages moved on railways, as a uniform and constantly retarding force,

That there is a certain area of bearing surface compared with the insistent weight when the resistance is a minimum,

That when the area of bearing surface is apportioned to the insistent weight the friction is in strict ratio to the weight.

There is no doubt that the friction of the well constructed carriages now used on public railways, with self-lubricating apparatus, is much less than the above amount. Indeed, some of the experiments then made upon the wagons used on the colliery railways showed the entire resistance not more than the $\frac{1}{240}$th part of the weight. It was my opinion then, and subsequent experience has shown that it is more safe in practice to adopt the previous conclusion for such wagons in the condition in which they are generally found on private railways.

In pursuing the enquiry, therefore, of the economy of the underground railway system, I shall adopt the same course of proceeding, and not give results derived from well-built carriages fitted up for the occasion, but shall give experiments made with carriages promiscuously taken from the stock actually at work at the collieries when the experiments were made. In following this course we proceed on safe grounds, as dependence may be placed on results thus derived in their application in practice.

The following are experiments made at different Collieries in the Counties of Northumberland and Durham on the Friction of the tubs used at those Collieries:—

No. 1.—*EXPERIMENT made in the Main Coal Seam, Hetton Colliery, March,* 1855.

No. of Experiment.	No. of Full Tubs.	Time.	Length of Plane.	Total Fall.	Fall per Yard.	Inclination of Plane.	Weight of Tubs.	
		Min. Sec.	Yards.	Inch.	Inch.		lbs.	
1	3	1 — 10	188	60·6	·32	1 in 125	4158	
2	3	1 — 20	194	62·	·32	1 .. 112	4158	
3	6	1 — 20	169	58·5	·34	1 .. 104	8916	Weight of each Tub.
4	6	1 — 12	161	61·	·37	1 .. 95	8916	Empty Tub .. 463lbs.
5	4	1 — 10	159·5	63·25	·39	1 .. 90	5544	Coals..... 923 „
6	4	1 — 15	182	53·75	·30	1 .. 119	5544	Total..1366lbs.
7	1	1 — 15	212	53·5	·25	1 .. 142	1386	
8	1	1 — 18	208	53·5	·25	1 .. 139	1386	
Average	28	1 — 15	184·2	58·5	·32	1 in 108	5001	

In the above experiment the gradient of the plane on which the tubs were placed was just sufficient to put the tubs in motion, and they were allowed to run along the plane until they came to rest, the gradient on that part of the plane being a little less than where the tubs were set off. The length of the plane from where the tubs were started until they came to rest is given, as also the total fall in inches, with the rate of inclination.

The tubs starting from a state of rest, and coming to a state of rest again, the rate of inclination of the plane is the measure of the friction in parts of the weight. Hence the average of these experiments shew the friction to be equal to the $\frac{1}{108}$th part of the weight. The wheels, when new, being 12 inches, and the axles 1·3775 inches, the ratio being 8·73 : 1. The road was laid with rails, having a round top, and was in good condition. The variation in the experiments arose from the condition of the tubs, and whether well greased or not.

No. 2.—EXPERIMENT made in the Stone Drift, Minor East Pit, Hetton Colliery, March, 1855.

No. of Experiment.	No. of Full Tubs.	Time.	Length of Plane.	Total Fall.	Fall per Yard.	Inclination of Plane.	Weight of Tubs.	
		Min. Sec.	Yards.	Inch.	Inch.		lbs.	
1	3	1 — 0	143·5	11·25	·78	1 in 45	4167	
2	3	1 — 16	178·5	118·5	·66	1 .. 54	4167	
3	6	1 — 20	156·	114·12	·73	1 .. 49	8322	Weight of each Tub.
4	6	1 — 17	189·5	121·	·63	1 .. 57	8322	Empty Tub .. 465lbs. Coals..... 923 ,,
5	8	1 — 21	198·	123·	·62	1 .. 62	11096	
6	8	1 — 17	152·	114·25	·75	1 .. 75	11096	Total..1388lbs.
7	1	1 — 20	171·	119·	·69	1 .. 69	1387	
8	1	1 — 6	131·5	114·5	·86	1 .. 41	1387	
Average	..	.....	....	....	....	1 in 53		

This experiment was performed in the same manner as No. 1 experiment, but in this case the diameter of the wheels of the tubs was 7·5 inches, the axles 1·3775 inch, the ratio being 5·5 : 1, and the road had also been at work for some time. The tops of the rails being quite flat, and the road, though in good working order, not in the best, but in ordinary condition. These experiments shew the friction to be equal to the $\frac{1}{53}$rd part of the weight.

No. 3.—EXPERIMENT made in the Old Polka Way Elemore Colliery, March, 1855.

No. of Experiment.	No of Full Tubs.	Time.	Length of Plane.	Total Fall.	Fall per yard.	Inclination of Plane.	Weight of Tubs.	
		Min. Sec	Yards.	Inch.	Inch.		lbs.	
1	10	1 — 30	153	62·25	·406	1 in 90	13860	Weight of each Tub.
2	10	1 — 30	122	55·62	·45	1 .. 80	13860	Empty Tub .. 463lbs. Coals..... 923 ,,
3	10	1 — 37	119	55·25	·46	1 .. 77	13860	
4	3	1 — 37	151	62·5	·41	1 .. 87	4158	Total..1386
5	1	1 — 30	125½	56·45	·45	1 .. 80	1386	
Average	..	.....	....	....	....	1 in 82·7		

This experiment was made in the same manner, upon a piece of road which had been for some years in use, and where the rails were quite flat on the top. The road being in ordinary condition. The diameter of the wheels and axles being the same as in No. 1 Experiment, wheel 12 inches, and axle 1·3775 inch, ratio 8·73 : 1. The average inclination of the plane in the experiment being 1 in 82·7, while it was only 1 in 108 in Experiment No. 1, shews the difference of friction between an ordinary road, with flat top rails, and a newly laid road, in good condition, with a round top rail.

No. 4.—*EXPERIMENT made on the Friction of Tubs at Black Boy Colliery, 24th March,* 1855.

A piece of road was selected, where the inclination was such, that the tubs just run of themselves, having a fall of 1 foot 10 inches in a distance of 50 yards. An empty tub set in motion, continued its motion down the plane, which it traversed in 28 seconds, or at the rate of about $3\frac{3}{4}$ miles per hour. The resistance thus shewn would be equal to the $\frac{1}{82}$ part of the weight.

Diameter of wheel, 10 inches, } ratio, 7·27 : 1
„ axle, 1·375 inches, }

On another plane of one in eighty, the tubs run down at about the same velocity.

In the above experiment the gravitation of $\frac{1}{82}$ caused the tubs to describe a space of 50 yards in 28 seconds, which is the measure of friction.

No. 5.—*EXPERIMENT on the Friction of Tubs at Killingworth Colliery, 3rd April,* 1855.

The same process was adopted in this experiment as in the preceding. A piece of road was selected where the tubs just continued in motion when moved from a quiescent state, and the following was the result, road in good ordinary state:—

Length of plane, 93·5 yards. Descent, 3·42 feet,

the ratio of inclination being 1 in 82, which is assumed as the measure of friction.

Diameter of wheels, 11·5 inches, } ratio, 7·66 : 1.
„ axles 1·5 inches, }

No. 6.—EXPERIMENT on the Friction of Tubs at Andrew House Colliery, March, 1855.

This experiment was conducted in the same manner as the previous experiments. The road was in good ordinary condition, with flat top rails, when it was found that at an inclination of 1 in 73 the tubs when put in motion continued without any acceleration of velocity, making the friction the $\frac{1}{73}$ of the weight.

Diameter of wheels, 10·25 inches,
" axles, 1·375 inches, } ratio, 7·5 : 1.

No. 7.—EXPERIMENT on the Friction of Tubs at Crook Bank Colliery, March, 1855.

This experiment was made in the same manner, the inclination selected was 1 in 80. The road was in good condition, round top rail. The friction would appear therefore to be equal to the $\frac{1}{80}$th part of the weight.

Diameter of wheel, 8 inches,
" axle, 1·375 inches, } ratio, 1 in 6 nearly.

The previous experiments were made upon planes just equal to the friction of the tubs, and when the motion was very little, if at all, accelerated, hence the sine of the inclination of the plane gives the friction of the tubs. The following experiment was made with great care by Mr. Atkinson, upon planes, the rate of inclination of which produced an accelerated motion, the usual theorem in such cases being used to ascertain the friction.

No. 8.—EXPERIMENTS on the Friction of Underground Tubs or Wagons, at Pontop Colliery, by Mr. J. J. Atkinson, March, 1855.

The tubs or wagons were allowed to start from a state of rest near the bottom of an inclined plane, and the time occupied in their running a distance of 239·91 feet, with a fall of 9·35 feet in that distance, being an average gradient of 1 in 25·66, was ascertained by the vibrations of a pendulum.

The experiments were made on three different occasions and days, and were as follows:—

FIRST SET OF EXPERIMENTS.

Empty Tubs.	1st Tub,	29·33	Seconds.
	2nd "	26·29	"
	3rd "	28·82	"
	4th "	27·56	"
Full Tubs.	1st Tub,	27·30	"
	2nd "	25·53	"
	3rd "	27·30	"
	4th "	25·53	"

THIRD SET OF EXPERIMENTS.

Empty Tubs.	1st Tub,	27·5	Seconds.
	2nd "	26·7	"
	3rd "	27·1	"
	4th "	27·6	"
Full Tubs.	1st Tub,	26·0	"
	2nd "	27·5	"
	3rd "	26·0	"
	4th "	26·7	"

The second set of experiments were made by the Overman and back Overman.

SECOND SET OF EXPERIMENTS.

Full Tubs.	1st Tub,	27·3	Seconds.	Average state of lubrication.
	2nd "	26·3	"	
	3rd "	25·3	"	Newly greased.
Empty Tubs.	1st Tub,	28·3	"	Average state of lubrication.
	2nd "	31·4	"	
	3rd "	27·3	"	Newly greased.

The following is the formula by which the friction of the tubs is ascertained :—

Let d = the total length of the plane in feet.

h = the total height of the plane in feet.

t = the time occupied in traversing the plane, in seconds.

g = a measure of the force of gravity in a vertical direction = $16\frac{1}{12}$, being the number of feet through which that force urges a body in the first second of time.

Then $\frac{h}{d}$ is the force of gravity resolved into the direction of the plane, being the sine of the angle of the inclination of the plane to the horizon. And from a well known theorem $\frac{d}{t^2 g}$ is the actual preponderating force urging the body down the plane, expressed in fractional parts of the force of gravity, when it is less than that force.

And hence $\frac{h}{d} - \frac{d}{t^2 g}$ is the force lost by frictional or other resistances, also expressed in terms of the force of gravity, by means of which expression the results of the experiments have been calculated, as embodied in the following table, which also exhibits the observed times of descent.

Table of the result of EXPERIMENTS on the Friction of Coal Tubs on Underground Railways, as tried in the Main Coal Seam at Pontop Colliery.

No. of Experiments and of Tub.	Load in the Tubs or the contrary.	Time of descending the plane in seconds.	Friction or retarding force in terms of the entire force of gravity $= \frac{h}{d} - \frac{d}{12\,g}$		REMARK.
			In Decimal notation	In Vul. Fractions	
1	Empty.	29·33	·02190001	$\frac{1}{45.663}$	The Tubs were not specially greased, but were supposed to be in their average state of lubrication during the experiments.
2	Do.	26·29	·01765641	$\frac{1}{56.637}$	
3	Do.	28·82	·02128065	$\frac{1}{46.981}$	
4	Do.	27·56	·01960035	$\frac{1}{51.03}$	
5	Full of Coals.	27·30	·01922436	$\frac{1}{52.017}$	
6	Do.	25·53	·01635184	$\frac{1}{61.173}$	
7	Do.	27·30	·01922436	$\frac{1}{52.017}$	
8	Do.	25·53	·01635184	$\frac{1}{61.173}$	
AVERAGES OF THE ABOVE EXPERIMENTS.					
4	Empty.		·02010935	$\frac{1}{49.733}$	
4	Full.		·01778810	$\frac{1}{56.217}$	
8	Full & Empty.		·01894872	$\frac{1}{52.774}$	

Diameter wheel, 11·5 } ratio, 1 : 8·36
„ axle, 1·375 }

The above set of experiments were made upon rails having a flat top and much worn, and the friction, though not more, perhaps, than the ordinary underground roads in the district, being very considerable. A piece of road was selected having round top rails, and where the road was in good condition, and the following experiments were made for the purpose of ascertaining the difference of resistance between the flat top rail, with a road not particularly straight, or in first-rate condition; and with round top rails, and the road straight and in good condition.

No. 9.—Account of EXPERIMENTS made at Pontop Colliery to ascertain the Friction of Underground Tubs or Wagons, on the 9th and 13th April, 1855.

The tubs were allowed to start from a state of rest, and the time was

ascertained during which they traversed a distance of 147 feet with a total fall of 3·83, being an average gradient of 1 in 38·38.

EMPTY TUBS. No. of Experiments.	Time in Seconds.	FULL TUBS. No. of Experiments.	Time in Seconds.
1	24	1	24
2	26	2	26
3	24	3	26
4	24	4	23
5	23	5	22
6	25	6	22
7	24	7	23
8	24	8	21
9	24	9	21
10	23	10	21
11	23½	11	22
12	24	12	21
13	26	13	22
14	24¾	14	21
Average	24·2 seconds.	Average	22·5 secs.

$$\text{Now } \frac{h}{d} - \frac{d}{t^2 g} = \text{friction}$$

and hence $\frac{1}{95 \cdot 7}$ friction of empty tubs and $\frac{1}{125}$ friction of loaded tubs.

Nos. 8 and 9 Experiments being made with the same tubs, but upon different descriptions of rails, and with roads in different states of condition, shew the results to be greatly different. The average of the empty tubs being respectively $\frac{1}{49 \cdot 729}$ and $\frac{1}{95 \cdot 7}$, and of the loaded tubs $\frac{1}{56 \cdot 217}$ and $\frac{1}{125}$, the general average being as $\frac{1}{52 \cdot 774}$ to $\frac{1}{110 \cdot 35}$, shewing that with proper rails, and with a straight road and in good condition, the friction or resistance is reduced fully one-half.

The following is the result of all these Experiments.

No. of Experiment.	NAME OF COLLIERY.	Diameter of Wheels.	Diameter of Axles.	Ratio of Diameter of Wheels to Diam'tr of Axles.	Ratio of Friction to Weight.
		Inches.	Inches.		
1	Hetton Colliery, Main Coal.....	11·5	1·3775	8·7 : 1	$\frac{1}{108}$
2	Ditto, Minor Pit.....	11·5	1·3775	8 7 : 1	$\frac{1}{85 \cdot 7}$
3	Ditto, Elemore.....	7·5	1·3775	5·5 : 1	$\frac{1}{53}$
4	Black Boy Colliery.....	10·	1·375	7·27 : 1	$\frac{1}{82}$
5	Killingworth Colliery.....	11·5	1·4	8·21 : 1	$\frac{1}{82}$
6	Andrew's House Colliery.....	10·25	1·375	7·5 : 1	$\frac{1}{73}$
7	Crook Bank Colliery.....	8·	1·375	6· : 1	$\frac{1}{85}$
8	Pontop Colliery, No. 1.	11·5	1·375	8·7 : 1	$\frac{1}{52 \cdot 73}$
9	Ditto, No. 2.	11·5	1·375	8·7 : 1	$\frac{1}{110 \cdot 35}$

We thus see that with 11½ inch wheels, and with the road in good condition, and round top rails, the friction is about the $\frac{1}{109}$th part of the weight, while with rails worn on the top or flat top rails, and with the road in ordinary condition, the friction is about the $\frac{1}{82}$nd part of the weight. The difference arising entirely from the state of the road and the rails, indeed this is plainly seen by the sinuous motion of the carriages on roads in bad condition, and consequently the rubbing of the flanches of the wheels against the rails being very great. The result of wheels of 7½ inches in diameter, the friction on the ordinary roads is about equal to the $\frac{1}{53}$rd of the weight.

These are very startling results as regards the economy of the conveyance of coals underground, and which raises the very important question whether sufficient attention has been paid to the construction of the carriages, of their wheels, and of the roads whereon they have to travel. And it likewise points out, with undeniable force, the imperative necessity of considering with all the energies in our power, whether any, and what improvements can be made to diminish the resistance. Such a desideratum being the foundation of all economy in the transit of the coal from the workings to the shaft.

No doubt the height of the beds of coal, to a great extent if not wholly, determines the height of the wheels to be used; but, notwithstanding, we see that much may be done by a careful attention to the form of the wheels and rails, and to the condition of the roads.

These experiments agree to a considerable extent with the experiments made on the wagons at bank, hereinbefore alluded to, taking into consideration the difference in the diameter of the wheels and axles. These experiments give the resistance as equal to the $\frac{1}{200}$th part of the weight, in carriages of ordinary construction. The resistance of the wheels on the rails being equal to the $\frac{1}{1000}$th part of the weight; leaving the friction on the axle equal to the $\frac{1}{204}$th part of the weight. Thus:—

The resistance of the wheels on the rail being in the inverse ratio of the diameter of the wheels, and the friction on the axles being in the inverse ratio of the diameter of the wheels to that of the axle, we have, as regards the wheels, the ratio of 3 : 1, and as regards the friction on the axles, the wheels 3 feet diameter, and axles 3 inches in diameter, or the ratio of 12 : 1, to be compared with wheels of 12 inches diameter, and axles 1½ inches diameter, or the ratio of 8 : 1. Then:—

$(\frac{1}{1000} \times \frac{3}{1}) + (\frac{1}{204} \times \frac{12}{8}) = \frac{1}{96}$th part of the weight for the underground carriages with wheels of 12 inches and axles 1½ inches; which does not differ materially from the result of the experiments.

In the case of the experiment of Black Boy Colliery where the tubs and rails were in good condition, the ratio of the wheels and axles being 7·27 : 1, the wheels being 10 inches in diameter:—we have

$(\frac{1}{100} \times \frac{36}{10}) + (\frac{1}{204} \times \frac{12}{727} = \frac{1}{65}$th part of the weight; experiment giving the $\frac{1}{62}$nd part of the weight.

And again, in the case of the small wheels in the third experiment, the wheels being 8 inches in diameter when new, or 7½ inches in use:—we have

$(\frac{1}{100} \times \frac{36}{7.5}) + (\frac{1}{204} \times \frac{12}{5.5}) = \frac{1}{65}$th; experiment showing the $\frac{1}{53}$rd part of the weight. The increased resistance in this case, no doubt arising from the additional comparative resistance by the rubbing of the small wheels against the rails.

We may, therefore, I think, conclude that with wheels of 12 inches in diameter, and of axles 1½ inches, or with a ratio of 8 : 1 the friction on the ordinary railways underground is equal to the $\frac{1}{62}$nd part of the weight; but that with well constructed roads, wheels and carriages, the friction may be reduced to the $\frac{1}{100}$th part of the weight; and that with wheels of 8 inches in diameter, the ratio of the diameter of wheels and axles being 6 : 1, the friction on ordinary roads will be equal to the $\frac{1}{53}$nd; and on well-constructed roads, and proper wheels and carriages, the resistance may be reduced to the $\frac{1}{65}$th part of the weight; and so in proportion to any other size of wheels.

Since writing the above, Mr. Sinclair, late Secretary to the Institution, and now Mining Engineer to the Tredegar Coal and Iron Works in South Wales, has forwarded to me some experiments which he has made on the friction of the trams used at those works.

He says, "with a tram, the wheels of which were such as could be either used on a tram-road or edge rail, 15 inches diameter, I found on the edge rail it required an inclination of 1 in 70 to move the empty tram weighing 960 lbs.; and an inclination of 1 in 59 to move the loaded tram weighing 3360 lbs."

Also, "I tried the following experiment. I had the way laid down perfectly level, and placed a pully at the end; I then attached the tram to a string, which went over the pully; and I found it required a weight of 12lbs. to move the empty tram of 960lbs., or $\frac{1}{80}$th part of its weight; and 32lbs. to move the loaded tram of 2160lbs., or $\frac{1}{68}$th part; and 52lbs. to move the tram when weighing 3360lbs., or $\frac{1}{65}$th part of its weight."

Mr. Sinclair subsequently made the following experiments. Wheel 15 inches diameter, on edge rail. Empty tram 1226lbs., 15lbs. or $\frac{1}{82}$nd; loaded with 1200lbs., making 2426lbs., 32lbs. or $\frac{1}{76}$th; and loaded with 2400lbs., making 3626lbs., 51lbs. or $\frac{1}{71}$st part of the weight.

And on Tram plate, diameter of wheels 19 inches, empty tram 880lbs., 9lbs. or $\frac{1}{98}$th; loaded with 1200lbs., making 2080lbs., 26lbs. or $\frac{1}{80}$th; and loaded with 2400lbs., making 3280lbs., 47lbs. or $\frac{1}{70}$th of its weight. These wheels are loose on the axle, and the axles also turn round. In all these experiments the wheels and axles were well cleaned and oiled.

MOTIVE POWER USED ON UNDERGROUND RAILWAYS.

It need scarcely be stated that locomotive engines cannot be employed to travel upon the railways underground. It has been previously stated that the average height of the coal beds, at least in the counties of Northumberland and Durham, is not more than four feet. It is true in Staffordshire there is a bed of coal, or rather a series of beds, in one mass of about thirty feet in height, but besides the question of height there are other insuperable difficulties in the way of using locomotive engines underground, viz., the effect of the heat and steam on the passages or air-courses, and on ventilation of the mine, and likewise on the health of the miners employed therein.

We are thus precluded from the use of the best and most economical power for the conveyance of the coals underground, and at present the conveyance is confined to Boys, Ponies, Horses, Gravity or Self-acting Planes, and Fixed Steam Engines. The *Boys and Ponies* being employed in bringing out the coals from the face of the workings to the main roads, —*Horses* on the level or nearly level parts of the main road,—*Self-acting Planes* where the inclination of the beds of coal is such that the gravitating power of the loaded tubs or carriages, is such as to overcome their friction, the friction of the empty tubs, their gravity, and the friction and gravity of the rope and sheaves on which the rope runs,—and *Fixed Steam Engines* used for dragging the coals up from the deep workings, and more recently along the level, or undulating roads where horses were formerly exclusively used.

BOYS AND PONIES.

Taking each of these in rotation, I have stated that boys are employed

to convey the coals from the workings of the mine to the main roads, a distance generally of from one to two hundred yards, where, from the height of the bed of coal, and from the intricacies of the workings, horses cannot beneficially be employed. Generally, and until within the last few years, boys alone were employed, taking one tub containing from six to nine cwts. of coal at a time, and conveying from forty to fifty tubs per day, and thus travelling from eight to ten miles per day. Latterly, or within the last few years, small ponies have been used to drag the tubs, smaller boys being employed to drive the ponies, which are generally three feet six inches to four feet in height, and thus the coals are conveyed from the workings to the main roads.

Where the inclination of the beds of coal is moderate, the boys, or ponies, convey the coals from the workings with great ease, but where the inclination is considerable it is a more difficult undertaking, the coals cannot be brought out of the dip workings without the use of strong ponies or horses; and the operation of bringing the coals from the rise workings on a steep inclination is very difficult, first, in preventing the trams or carriages from over-running the boys, or ponies, and next in the power required to convey the empty tubs up the plane.

An apparatus, on the principle of a self-acting plane, has been in use at the Killingworth Colliery, introduced by Mr. John Liddell, which has answered the purpose very well, when the inclination is about 1 in 3 or 4.

Figs. 1 and 2, plate II, shews this apparatus. A prop is placed near the face of the working, to which is fastened the sheave B, the other end being steadied by the short prop cut into the floor of the mine. A counter-balance carriage W is made to run up and down a narrow railway, two feet in width, on one side of the bord, the rope from which is passed round the sheave, as shewn in the drawings, the other end of the rope being attached to the tub D. The counter-balance carriage is loaded so that the gravity assists in dragging the empty tubs up the plane, and this drag prevents the loaded trams from over-running the boys or ponies in their descent to the main roads. The prop A and the apparatus is removed forward every night as the coal is excavated, so that the trams are brought close to the face of the working, and this is done with very little trouble and expense. The counter-balance carriage rests against the prop E when at the bottom of the plane near the main levels, and it passes into the depression F when at the top, so that no brake is required to cause it to remain at rest when not in action. By this apparatus large quan-

tities of coals are brought down from the workings at the inclination above stated, of 1 in 3 or 4, with almost the same power as upon a level road.

HORSES.

It has already been explained that horses have been generally used on the main roads, or water levels, or on roads not materially varying therefrom. The comparatively small power which a horse is capable of exerting renders it impracticable, consistently with economy, to employ horses upon inclined roads where the gravitation of either the empty or loaded tubs present any considerable amount of resistance.

It becomes, therefore, of importance to ascertain, on what inclination of road, under all the circumstances which can arise underground, horses can perform a maximum effect; so that in practice we may endeavour to lay out the roads to that rate of inclination; and to avoid deviation therefrom as much as practicable.

The rate of inclination at which water will flow in a mine, subjected to the casual interruptions incident to such cases, is about 1 in 260, or about an eighth of an inch in a yard. This may, therefore, be said to be the ruling gradient of horse roads generally, the water levels, as previously stated, being generally used as horse roads. We have found the friction of the tubs to be equal to the $\frac{1}{80}$th part of their weight in one case, and about the $\frac{1}{60}$th part in another case.

In almost all the cases in underground traffic the load is entirely in one direction towards the bottom of the pit; the empty carriages being the only resistance in the opposite direction to the workings. And we may take generally the empty tubs to be equal to 3 cwt., and the weight of coals 9 cwt., making the weight loaded 12 cwt., and empty 3 cwt.

The inclination of road which will make the resistance equal in both directions, supposing the friction to be equal to the $\frac{1}{80}$th part of the weight, will, therefore, be $\frac{12}{3} = 4$ and $\frac{4-1}{4+1} = \frac{1}{1{\cdot}666}$ and $\frac{1}{1{\cdot}666} \times \frac{1}{80} = \frac{1}{133}$ the inclination when the resistance is the same in both directions. And if the friction is equal to the $\frac{1}{60}$th part of the weight, then $\frac{1}{1{\cdot}666} \times \frac{1}{60} = \frac{1}{100}$ the inclination of the road.

In the experiments on the power of horses dragging carriages on railroads above ground, I arrived at the conclusion that a horse was capable

of exerting a force of 120 lbs., travelling at the rate of 2 to 3 miles an hour, and that he was capable of continuing that exertion for 10 hours, or for 20 miles in each day, when the load and resistance was equal in both directions; or that he was capable of exerting a force equal to 180 lbs. in one direction, and 60 lbs. in the other, when the load was in one direction only, and when the stages were not long, performing, in the latter case, also 20 miles per day.

If the ratio of the weight of the loaded to the empty carriages be as 3 : 1, we have the inclination to cause the resistance to be the same in both directions; the friction being equal to the $\frac{1}{200}$th part of the weight $\frac{3-1}{3+1} \times \frac{1}{200} = \frac{1}{400}$ the inclination of the plane.

The weight, therefore, which a horse would drag on a level road, exerting a force of 120lbs in both directions, would be 120 × 200 = 24000lbs. or 10 tons for 20 miles, or a gross performance of 200 tons one mile per day; and of useful performance $\frac{2}{3}$rds or $6\frac{2}{3}$ tons per 20 miles, or $133\frac{1}{3}$ tons one mile, which may be termed the maximum practical performance.

If the load is only in one direction and level, and a horse exerts 180lbs. with the load, and 60lbs. with the empty carriages, then the useful performance will be 10 tons conveyed 10 miles per day, or 100 tons conveyed one mile; but, if the inclination of the road is such as to make the load equal in both directions, or 1 in 400, then a maximum effect will be produced, and the useful performance will be $133\frac{1}{3}$ tons conveyed one mile.

I shall now give some cases of the performances of horses employed in the conveyance of coals underground:—

1.—HETTON COLLIERY, ELEMORE PIT.

Weight of empty tubs 4 cwts. each.
" loaded tubs $12\frac{1}{2}$ cwts. each.

	Chains.		Chains.			Chains.
1st stage,	31 × 2	=	62 ×	9 trips per day	=	558
2nd do.	53 × 2	=	106 ×	9 do.	=	954
3rd do.	70 × 2	=	140 ×	17 do.	=	2380
4th do.	47 × 2	=	94 ×	18 do.	=	1692
				Total distance travelled		5584

Seven horses were employed, therefore $\frac{5584}{7} = 800$ chains nearly, or equal to ten miles per day each horse. The load of each horse was fourteen tubs of 12½ cwt. each loaded, and 4 cwt. each empty. Supposing the inclination of the road such as that the resistance was equal in both directions, and that the friction was equal to the $\frac{1}{80}$th part of the weight, the wheels being 12 inches in diameter, the resistance would be 162lbs. for ten miles a day, or a performance of 1,620lbs. moved one mile in a day; and the useful performance 5 tons 19 cwt. conveyed five miles per day, or 29·75 tons conveyed one mile per day.

In this experiment the horses had to go to several stations, which caused great delays, and consequently the distance travelled was very small, though the resistance was more than ordinary. This was a single line with sidings.

HETTON COLLIERY, ELEMORE PIT.

This was a piece of road of 1,280 yards in length, to one station only, and the road was double. In this case the horses took 14 tubs, of the same weight as the former experiment. There were 8 horses employed, and they performed 99 journeys, which is equal to 17·22 miles per day for each horse, with an uniform resistance of 162lbs., and is equal to a performance of 2,789lbs., moved one mile each day, the useful performance being 5 tons 19 cwts., conveyed 8·61 miles per day, or 51·23 tons conveyed one mile per day. The horses were very powerful, and the road was kept in excellent order, therefore the resistance was probably less than the estimated amount of friction. This now forms the engine plane of the Elemore Colliery, shewn in figs. 3 and 4, plate I.

HETTON COLLIERY, MINOR PIT.

This is a stage of 990 yards in length, on which seven horses were employed, performing 100 journeys per day, the number of tubs taken at a time being 9, of 4 cwt., empty, and 12½ cwt., loaded. These tubs have 8-inch wheels, the friction being about the $\frac{1}{60}$th part of the weight. The performance, therefore, is an average effect of 138·6lbs., moved sixteen miles a day, or 2217·6lbs., moved one mile per day, and the useful performance 3·825 tons conveyed eight miles a day, or 30·6 tons conveyed one mile per day.

ANDREWS HOUSE COLLIERY.

This experiment was made at the end of the engine plane, shewn in Fig. 8, Plate I. One horse dragged 11 loaded tubs out, taking the same number back again empty. The weight of the loaded tubs was 144 cwts. 1 qr. 21 lbs., and of the empty tubs 58 cwts. 1 qr. 21 lbs. The inclination of the road was 1 in 122, descending in the direction of the load. The number of journeys each day was 57 for one horse, and the distance being 285 yards, consequently the total distance travelled was nearly fifteen miles per day, friction of tubs $\frac{1}{13}$rd part of their weight.

	Cwts.	Qr.	lbs.		lbs.		lbs.
Then	144	1	25	$\times \frac{1}{222} =$	73	gravity,	= 148 resistance, loaded.
				$\times \frac{1}{13} =$	221	friction,	
And	58	1	21	$\times \frac{1}{222} =$	30	gravity,	= 120 resistance, empty.
				$\times \frac{1}{13} =$	90	friction,	

Mean resistance 134lbs., moved fifteen miles per day, which is equal to 2,010lbs., moved one mile per day; and the useful performance is 7·22 tons, conveyed 7·5 miles per day, or 54·15 tons conveyed one mile for such horse. It must be remarked, however, that this was under very favorable circumstances, as the horse was not detained at each end, and the gradient was about 1 in 100.

MARLEY HILL COLLIERY.

At this Colliery there are four stages, viz.:—

	Chains.		Trips.		Chains.
Gibside,	69·7	×	34	=	2369·8
Crosscut,	105·5	×	24	=	2532·0
Central,	108·0	×	22	=	2376·0
No. 9,	100·5	×	22	=	2211·0
Total distance travelled .				..	9488·8

Fifteen horses are employed, therefore $\frac{9488 \cdot 8}{15 \cdot}$ = 632 chains, or 7·9 miles × 2 = 15·8 miles per day each horse. The number of tubs taken at a time was 10; the loaded tubs 13 cwt., and the empty tubs 5 cwt., consequently the useful performance was 7·9 miles × 4· tons = 31·6 tons conveyed one mile per day; the load being all in one direction.

These are two cases where, besides conveying the coals along the stages, the horses in the first case have to drag the trams from the top of the engine plane to the shaft, a short level stage of 100 yards only; and also to take the trams from another flat to the shaft, the stage being 560 yards, and the inclination against the load 1 in 80, which is a very disadvantageous application of horse power. And in the second case, the horses take the trams from a pony flat to the landing, where the engine drags them along a stage of only 572 yards, and the horses have also to drag the empty engine set into the landing. Three horses are employed in the first case, the number of journeys per day being 63 on the 100 yard stage, and 15 on the 560 yard stage. The load in both cases is eight tubs, the weight of the empty tubs being 3½ cwt., and when loaded 11½ cwts. These tubs have 10-inch wheels. Supposing the friction to be equal to the $\frac{1}{80}$th part of the weight, then the resistance, with the load, up the stage of 572 yards, will be 232lbs., and on the level 116lbs, the relative distances travelled being 8,580 and 6,300 yards, the mean resistance will be 183·5lbs., which is the maximum practical performance of a horse above ground. The useful performance by the short stages, and delays at the termini, being only 3·9 tons, conveyed 2·8 miles, or 10·92 tons conveyed one mile for each horse.

On the stage of 572 yards, four horses are employed, the number of journeys per day being 67, and the load 6 tubs, the road being undulating but generally level, the weight of the tubs and coals the same as in the last experiment. The useful performance in this case is 2·8 tons, conveyed 5·45 miles per day, or 15·26 tons conveyed one mile by each horse.

The following table will shew the performances of horses under-ground in these several cases, and also the performance of horses above-ground with the ordinary coal wagons:—

TABLE OF THE PERFORMANCE OF HORSES UNDERGROUND.

LOCALITIES.	Number of Horses.	Length of Horse Roads.	Number of Trips per Day.	Diameter of Wheels.	Inclination of Horse Road.	Weight of each Tram.		No. of Trams in each Trip.	Average performance of each Horse per Day.		Tons conveyed by each Horse, One Mile per Day.
						Loaded.	Empty.				
		Yards.		Inches.		Cwts.	Cwts.		Tons.	Miles.	
Elemore Colliery.....	7	682 1166 1540 1067	9 9 17 18	12·	1 in 130	12·5	4·	14	5·95	5·	29·75
Ditto	8	1280	99	12·	1 in 202	12·5	4·	14	5·95	8·61	51·23
Hetton Colliery.....	7	990	100	8·	1 in 130	12·5	4·	9	3·825	8·	30·6
Andrew's House Colliery	1	285	57	10·25	1 in 222	13·013	5·3	11	7·22	7·5	54·15
Morley Hill Colliery....	15	2046	102	10·	1 in 144	13·	5·		7·9	4·	31·6
Springwell Colliery	3	100 560	63 15	10· 10·	Level. 1 in 80	11·5	3·5	8 15	3·9	2·8	10·92
Ditto	4	572	67	10·	Level.	11·5	3·5	6	2·8	5·45	15·26
Above ground	1	1760	10	36·	Level.	75·	25·	6	10·	10·	100·
	1	1760	10	36·	1 in 400	75·	25.	8	13·33	10·	133·33

It will be seen from the foregoing table that the generally useful performance of a horse under-ground is not more than one-third of the ordinary, or one-fourth of the maximum useful performance of a horse on the colliery railways on the surface. The second case of Elemore Colliery is an exception, the performance there amounting to one-half, but this case was a peculiar one, the road was in excellent condition, it was double from end to end of the stage, and there was not, consequently, those stoppages at the passing places and at the ends of the stage which so materially diminish the useful performance of a horse under-ground. The horses employed on this work were powerful ones, and required great feeding to keep them in good working condition; and the same is the case at Andrew's House Colliery.

I shall now give the performances of horses employed under-ground on the tram-roads in South Wales, which I have been favoured with by some of the managers of the extensive coal and iron works in that district of the country.

The following table is an abstract of the performances of horses in 61 coal and iron-stone levels, which I have compiled into the same form as that of the performances of horses in the County of Durham.

TABLE OF THE PERFORMANCE OF HORSES UNDER-GROUND, IN SOUTH WALES.

DESCRIPTION OF ROAD.	Number of Horses.	Average Length of Horse Roads.			Average No. of Trips, per Horse per Day.	Diameter of Wheels.	Inclination of Horse Roads.		Average No. of Trams in each Trip.	Weight of each Tram.		Average performance of each Horse per Day.		Tons conveyed by each Horse, One Mile per Day.
		Water Levels.	Rise Headings.	Dip Headings.			Water Levels.	Headings.		Loaded.	Empty.			
		Yards.	Yards.	Yards.		Inches.				Cwts.	Cwts.	Tons.	Miles.	
Tram-road.....	65	1807	90	51	3·43	20·5	1 in 264	1 in 10	3·	30·92	11	2·864	3·547	10·159
Edge Rail-road.....	71	1527	93	90	3·5	17·	1 .. 264	1 .. 10	3·	32·	11	3·15	3·4	10·710
Tram-road.....	46	1139	122	..	4·81	21·	1 .. 100	1 .. 12	4·33	25·	7·25	3·877	3·44	12·073
Tram-road.....	32	564	855	151	3·8	18·	1 .. 144	1 .. 12	3·58	30·3	8·	3·528	3·389	11·956
Tram-road.....	13	1256	193	45	3·99	19·	1 .. 144	1 .. 12	3·87	26·7	7·5	3·846	3·809	14·649
Tram-road.....	27	1335	419	..	3·236	17·	1 .. 264	1 .. 10	5·27	28·	8·	5·269	3·225	16·923
Edge Rail-road.....	23	480	703	..	3·075	17·	1 .. 264	1 .. 10	7·39	28·	8·	8·643	2·067	17·865

The above table is a most important contribution to our information of the performances of horses in the South Wales District, and exhibits, very conclusively, the necessity of improvements in the economy in the conveyance of the coals and minerals under-ground in that part of the country.

It is necessary to explain, however, that, as will be seen on examining the table, the reason for such a diminished performance is not so much from the small load which is taken at a time, as from the short average distances which the horses travel; and this is owing, in a great degree, to the practice in that country of taking the trams into the working places with the same horses which take them along the levels, by which great delay of time is occasioned; and also from all the levels being single, with passing places, not very frequent, and which is likewise the cause of considerable waste of time, so that the average distance which a horse travels in each day is little more than 6½ miles.

There is no doubt that the state of the levels, and of the trams also, contribute to produce this low standard of performance. The levels are mostly those which have been driven for the drainage of the mines, and as before remarked, are extremely crooked and tortuous, following all the sinuous undulations of the inclination of the strata, and are mostly tram-roads, and very liable, from the water in the levels, and from occasional falls from the roof and sides, to be not in good condition. The trams are not, likewise, well constructed, the wheels are almost generally loose on the axles, and there is not much pains taken in fitting them up. The more recently made roads are in better condition, and the trams are fitted up with more care, so that there is no doubt a more favourable result will shortly be accomplished. Still the performances of the horses, and consequently the very great cost in the conveyance of the coals and minerals in this district, demand that every investigation of which the subject is capable, is incumbent on the Mining Engineers of the present day, and which it is trusted this inquiry may be the means of promoting.

There does not seem, at first sight, by these tables, so great a benefit from the adoption of the edge rail, as will appear from a short investigation. Taking the two first cases, the difference is about ten per cent., but the wheels of the trams are 20½ inches, whereas the wheels of the edge rail trams are only 17 inches. In the last two cases, where the wheels are the same diameter, the difference is equal to fifty per cent. The performance in the last case is quite equal, in respect of the load taken, to that of the roads in Durham, except that in the latter cases the wheels are from 8 to 12 inches, whereas in the former they are 17 inches in diameter. But the falling off in the distance travelled is very striking, and can only be attributed to the causes which I have pointed out.

The general result, however, both in Durham and South Wales, points out with irresistable force the great necessity, in an economical point of

view, of the substitution of machinery for horse labour, in the conveyance of coals and minerals under-ground. For, if it has been thought advisable almost, if not entirely, to supersede the use of horse labour in the conveyance of minerals on the surface, where the performance of a horse is so much greater than under-ground, how much more then is it necessary for such a substitution under-ground, where the performance of horses is so extremely deficient and their employment so costly.

SELF-ACTING PLANES.

The next subject for consideration in the conveyance of coals under-ground is the employment of self-acting planes, where the gravitation of the loaded carriages or tubs is sufficient to overcome, 1. The friction and gravitation of an equal number of empty carriages or tubs. 2. The friction of the rope wheel, and sheaves, and the rope whereby the plane is worked, and to leave a sufficient surplus of force to perform the operation of letting down the loaded, and dragging up the empty carriages in a given time.

This description of power is the cheapest of all power used in the conveyance of coals underground, either animal or mechanical; and it is, consequently, of the greatest importance to ascertain to what extent, and under what circumstances it can be employed. It can only, of course, be used when the coals have to be brought from a higher to a lower level, and where the inclination is such as to produce the requisite gravitating power, and hence it will be necessary to inquire at what rate of inclination, and under what circumstances such a power can be employed.

The theory of the action of self-acting planes is well understood. The moving power G is the gravitation of the loaded carriages W, multiplied into the Sine of inclination of the plane, consequently $G = W \text{ Sin. } I$. There is, then, opposed to this—the gravitation of the empty carriages $g = w \text{ Sin. } I$, w representing the weight of the empty carriages, added to the friction of the loaded carriages F, the friction of the empty carriages f, and the friction of the rope wheel, rope and sheaves on the plane n, consequently, when $G = g + F + f + n$, the moving power is equal to and balanced by the resistance. There is, then, a further balance of power required to overcome the *vis inertia* of the whole mass, and to cause the carriages to perform the descent and ascent of the plane in a given time. Let S = the space to be traversed or the length of the plane, $r = 16\frac{1}{12}$ feet, the space which a falling body descends in a second of time, and t the time of descent, and w′ the weight of the rope wheel, rope

and sheaves on the plane. Then, according to the well known law of falling bodies, $\frac{(W + w + w') \times S}{r\,t^2}$ = the force required to cause the trains to pass down and up the plane in the time t, which make G′. We have then G = the moving power opposed to g + F + f + n in all cases. If we, therefore, make F′ = g + F + f + n, we shall simplify the notation, and retaining G′ = the gravitating or surplus power requisite to cause the trains to traverse the space S in the time t.

$$\text{Hence } G' = G - F' = \frac{(W + w + w') \times S}{r\,t^2} \quad (1)$$

$$\text{and } S = \frac{G - F'}{W + w + w'} \times r\,t^2 \quad (2)$$

$$\text{likewise } t = \sqrt{\frac{(W + w + w') \times S}{G - F' \times r}} \quad (3)$$

$$\text{and Sin. } I = \frac{\frac{(W + w + w') \times S}{r\,t^2} + \overline{F + f + n}}{W - w} \quad (4)$$

I shall now give some examples in practice of cases where the inclination is the least which can be employed for this description of power. Where the inclination is considerable, or where it is such as always to produce a surplus power in G′, more than sufficient to cause the trains to traverse the space S in the time t, then no theoretical rules are necessary, the time t can always be regulated by the number of full and empty carriages; and recourse can be had to the brake if these cannot be so regulated as to produce the required speed, but upon the flat planes some calculations are necessary.

The following experiments were made on a plane of a very moderate inclination in the Elemore Pit, Hetton Colliery:—

The plane is, exclusive of the landings at top and bottom, 1565·1 feet in length, with an entire fall of 47 feet, or an average inclination of 1 in 33·3. It is perfectly straight, but not of an uniform inclination, having an increased inclination at the top, to put the trains into the requisite velocity, and is gradually diminished towards the bottom of the plane; which by producing an increased resistance to the empty carriages

at the top, and a diminished gravitation of the loaded ones near the bottom brings the trains to rest.

A section and plan of this plane is given in Plate I, Figs. 3 and 4, and the following are the experiments made, a portion of 389 yards in length being selected for the experiments, with a fall of 38·77 feet, or an inclination of 1 in 30.

EXPERIMENTS made on the Polka Inclined Plane, Elemore Colliery, March 14th, 1855.

No. of Exp.	No of full Tubs.	No. of empty Tubs.	WEIGHTS. Loaded Tubs.	WEIGHTS. Empty Tubs.	Time.	Length of Plane.	Height of Plane.	Descent per Yard.	OBSERVATIONS.
			lbs.	lbs.	min. sec.	feet.	feet.	inches.	
1	24	26	34·310	12·038	2·45	1167	38·69	1·2	Diameter of Wheels, 12 Inches. Diameter of Axles, 1.3775 Inches. Inclination of Plane 1 in 30.
2	24	26	34·502	12·038	1·55	1167	38·69	1·2	
3	24	26	34·406	12·038	2·0	1167	38·69	1·2	
4	24	26	34·406	12·038	2·11	1167	38·69	1·2	
5	24	26	34·406	12·038	2·2	1167	38·69	1·2	
6	24	26	34·406	12·038	2·58	1167	38·69	1·2	
7	24	28	34·406	12·964	3·20	1167	38·69	1·2	
Aver. of Nos. 1 2 3 4 5 6			34·406	12·038	2·18	1167	38·69	1·2	

The result of these 6 experiments, with 24 loaded and 26 empty tubs, is as follows:—The time of descent averaged 2 minutes 18 seconds; the weight of the descending load was 34·406 lbs., and the weight of the ascending load 12·038 lbs. The inclination of the plane was 1 in 30. We have, therefore, the gravity of the load or moving power G = 1146·8 lbs., and the gravity of the ascending load g = 401·3 lbs. The tubs had wheels of 12 inches diameter, and axles 1·3775 inches in diameter, and the road being in good condition with round top-rails, we may, therefore, assume the friction to be the same as that of similar wheels, tubs, and railway, as shown in the experiments in the main coal seam, viz.:—$\frac{1}{108}$th

part of the weight. This would make the friction of the loaded tubs $F = 318{\cdot}6$ lbs, and the empty tubs $f = 104$ lbs.

We have then

$$\frac{(W + w + w') \times S}{r\,t^2} = \frac{(34{\cdot}406 + 12{\cdot}308 + 3453) \times 1167}{16\frac{1}{12} \times 138^2} = 191{\cdot}15 \text{lbs.}$$

$= G'$ the force to cause the trains to traverse the space S in the time t.

And, therefore, $1146 - \overline{318{\cdot}6 + 104 + 401{\cdot}3 + 191{\cdot}15} = 131{\cdot}75$ lbs. the friction of the rope, rope-wheel and sheaves. The weight of the rope being 825 lbs., the rope-wheel 1120 lbs., and 2 of the sheaves in action at a time 1508 lbs. = 3453 lbs., consequently, the friction is equal to the $\frac{1}{26{\cdot}2}$th part of the weight.

Another experiment was made upon this plane, as will be seen in the table, with 24 loaded and 28 empty tubs. The result of which was that the sets were run in 3 minutes 20 seconds. This gives

$$\frac{(W + w + w') \times S}{r\,t^2} = 92{\cdot}68 \text{ lbs. } G'$$

and, consequently,

$$1146{\cdot}8 - \overline{318{\cdot}6 + 142{\cdot}86 + 401{\cdot}3 + 92{\cdot}68} = 191{\cdot}36 \text{ lbs.},$$

the friction of the rope, &c. The velocity of the carriages being much less than in the other experiments, and a difference in the greasing of the wheels of the tubs may account for the difference between this result and the former.

The number of tubs which are usually run down at a time in regular working is 24 loaded and 24 empty. The time of running being about 2 minutes. It will be seen, however, that in case of need, an additional number of tubs can be taken up, or a return load equal to the gravity and friction of 4 tubs, or a resistance equal to 77·72 lbs. The regular day's work of 12 hours is about 70 trips.

Taking the result of the first 6 experiments, and the every day's experience of the working of this self-acting plane, we may safely assume that such a power can be employed in the conveyance of coals underground at an inclination of one in thirty, with a speed of between 7 and 8 miles per hour; and that with 24 tubs, there is an excess of power equal to about $\frac{1}{15}$th part of the moving power, upon a plane about a quarter of a mile in length.

The following experiments were made at my request on an inclined plane at Pontop Colliery, by Mr. Atkinson, a plan and section of such plane being shown in figs. 5 and 6, plate I.

A space was marked out on the plane, the length being 1217·4 feet= S, the descent being 44·08 feet, making an inclination of 1 in 27·62. Thirteen loaded tubs were run against 13 empty tubs, and the following was the time of descent of seven sets of experiments:—

Vis.	1	205	seconds
	2	176	„
	3	204	„
	4	195	„
	5	180	„
	6	178	„
	6	175	„

Average time 188 seconds, nearly.

The weight of the loaded tubs is 19·695 lbs. = W, and the empty tubs 7·514 lbs. = w. The rope-wheel 1110 lbs., the rope 1303 lbs., and the sheaves 1145 lbs., together 3559 lbs. = w′. Consequently we have

$$G = \frac{19{\cdot}695}{27{\cdot}62} = 713\text{lbs.},\ g = \frac{7{\cdot}514}{27{\cdot}62} = 272\text{ lbs.}\quad F = \frac{19{\cdot}695}{125} = 157{\cdot}5\text{lbs.},$$

and $f = \frac{7{\cdot}514}{95{\cdot}7} = 78{\cdot}5$ lbs. The friction of the tubs having been ascertained by No. 9 set of experiments previously given.

$$\text{We have then } \frac{(W + w + w') \times S}{r\ t^2} = 65{\cdot}12 \text{ lbs. } G'$$

And, consequently, $713 - \overline{272 + 157{\cdot}5 + 78{\cdot}5 + 65{\cdot}12} = 139{\cdot}88$ lbs. the friction of the rope-wheel, rope, and sheaves, being about the 1-23rd of the weight.

Thirty-four runs is about the every day-work of this plane in twelve hours—16 loaded and 16 empty tubs forming the train in each run.

The experiments on this plane corroborate those of the Hetton plane, and also the conclusion arrived at, that, with the present tubs in use underground self-acting planes can be used at an inclination of 1 in 30. In this experiment the rate of speed was 1217 feet in 3 minutes and 8 seconds, which is at the rate of 5 miles per hour with 13 tubs only; whereas 16 tubs is the usual number used, which is a power equal to 23 per cent. greater.

FIXED STEAM ENGINES.

The next description of motive power used in the conveyance of coals underground is the *Fixed Steam Engine.*

This description of motive power has been used for several years. More than thirty years ago a series of engines were in use at Killingworth Colliery—the first one was placed near the bottom of the pit, which pumped water up a staple of twenty fathoms in depth, and the coals were also drawn up from the same level to the bottom of the pit by an inclined plane, a distance of about 500 yards.

On pursuing the workings further to the dip, another steam engine was, subsequently, placed at the point from which the former engine dragged the coals; and this second engine, which was erected at about 500 yards from the bottom of the pit, dragged the coals from a further distance of 500 yards, and from an increased depth of level of twenty fathoms.

And lastly, on the prosecution of the workings still further to the dip, a third engine was erected at the distance of 1000 yards, and at a level of about forty fathoms below the bottom of the pit; which engine dragged the coals a further distance of 500 yards, and at the increased depth of about thirty fathoms:—making altogether a series of engine planes dragging coals a distance of 1500 yards, and from a depth of level about eighty fathoms below that of the bottom of the pit.

And it may be also stated, that the water was likewise pumped from this extreme distance, and from the depth of eighty fathoms below that of the bottom of the pit, by a system of sliding wooden spears, and pumps laid down the drifts.

The boilers supplying the steam were placed at the stations where the engines were placed, the smoke being conveyed to the bottom of the pit, by drifts or flues prepared for that purpose.

With such an extensive application of engine power more than thirty years ago, it is rather a matter of surprise that such a power has not since that period been more extensively employed underground. There are no doubt instances of the application of engine power at a great many collieries in the trade, but these have, I believe, been almost exclusively confined to a single engine placed near the bottom of the pit, and drawing coals and water up a single plane from the deep workings. Until recently, no attempt has been made at the introduction or employment of the

steam engine underground, as a system of motive power in substitution of horse labour.

We have already seen that horse power underground is employed at a great disadvantage, as compared with the employment of horse power above ground, the efficient performance in the former case not being more than 50 per cent. of the efficient performance in the latter. When it is considered, therefore, that the principal cost of a steam engine is fuel, and that this article is in superabundance at all collieries, and that the fuel which is generally used by the steam engines at a colliery, can be obtained at a comparatively small cost; it is a subject of great importance how far the use of steam engines can, in an economical point of view, be employed in substitution of horse labour in the conveyance of coals underground. But it is likewise not of less importance to ascertain, to what extent it can be employed, and in what manner, in the conveyance of coals to the deep of the pits, and to a greater distance from the shaft, than it is practicable to accomplish economically by horses, and so likewise to supersede the cost of sinking pits.

In the investigation of this important question, in the economy of the conveyance of coals underground, I have obtained all the information in my power, and have had such experiments made, at the different collieries where engine power has been used, as will, I trust, enable me to exhibit to the Institute such information as will enable them to arrive at a correct practical conclusion on the subject.

The experiments embrace practical results in almost all the different applications, requisite to establish a complete system of fixed engine power in the transit or conveyance of coals underground, where it is advisable to resort to the use of such a system; and which, together with the aid of self-acting inclined planes; will present a system of mechanical power, for the conveyance of coals underground in any colliery, without the aid of horses, except as auxiliaries to those two mechanical powers.

Firstly—I shall therefore, first of all, give *experiments on the powers and capabilities of fixed engines employed in dragging coals from the dip*, where the inclination of the strata is such, that the empty carriages have sufficient gravitating power to drag the rope after them, and which is to be used in dragging the loaded carriages up the plane. This is the system already alluded to as having been practised in the trade for several years. I shall give experiments on engines of this description employed at Hetton, Killingworth, and Springwell collieries.

Secondly—I shall then give *experiments on the powers and capabilities*

of fixed engines used as substitutes for horse power along the level roads. The roads *rising* from the shafts, or bottom of the pits, to where the coals are to be brought from, and where hitherto horse power has been almost exclusively used; and these experiments will extend up to that inclination where the self-acting inclined plane comes into operation, or where it can be used. This section will, therefore, embrace the system of engine power conveyance, from a level or undulating road to the *rise*, or above the level of the pit, until the self-acting plane can be used.

Thirdly—I shall also give experiments on engines—practically the same, however, as those last described—used, from the level of the pit to such an inclination *dipping* from, or below the level of the pit, where such inclination is not sufficient to enable the empty carriages to drag out the rope, which is afterwards to be used by the engine in dragging the loaded carriages up the plane:—forming a system of engine planes between the water-level line to the *dip*, up to the point where engine power can be employed with a single rope in dragging coals from the deep of the mine, as in the first case;—and thus completing the system, in all the varieties, of fixed engine power underground.

The experiments which I shall give in illustration of the two last cases will be from engines actually employed at Killingworth, Hetton, Marley Hill, and Black Boy collieries.

In the investigation of the powers and capabilities of underground engines, the cases will comprise the application of engines, where the cylinders or power is placed underground, and where the boilers producing the steam is also placed underground. But it will likewise comprise cases, where the cylinders or power is placed underground, and where the boilers are placed on the surface, the steam being conveyed down the pit in pipes; and it will also comprise cases, where both the boilers and machinery are placed on the surface, and where the ropes dragging the load are taken down the pit.

The following are the experiments alluded to:—

No. 1. Experiments on engines dragging coals from the dip with a single rope:

HETTON, KILLINGWORTH, AND SPRINGWELL COLLIERIES.

No. 2. Experiments on engines dragging coals along the level roads where horses were formerly used:

HETTON COLLIERY ELEMORE ENGINE PLANE.

EAST MINOR PLANE.

KILLINGWORTH AND MARLEY HILL COLLIERIES.

No. 3. Where the engine is employed in dragging coals along the level, and likewise in a cross-cut direction, midway between the level and the full dip, where the first description of engines are employed:

BLACK BOY COLLIERY.

In the last case the engine is also employed in pumping water from the dip by a process which will be hereafter described—an operation which is very essential, if the extension of engine power is to be applied to supersede the frequent sinking of pits.

It was scarcely necessary perhaps to give drawings of any engines, as there are a great variety of forms of engines which may be used for the purpose. I have, however, thought it advisable, for the information of those who may not have had opportunities of seeing such description of engines in operation, to give drawings of two different kinds of engines which are actually at work; and I shall endeavour to illustrate, with the aid of those two drawings, the different applications of engine power requisite to complete the system of fixed engine power to which I have previously alluded.

Figs. I., II., and III., *Plate III.*, are the Ground Plan, Front Elevation, and End View of an underground engine which I have erected at the Black Boy colliery, near Bishop Auckland. The engine is placed underground, and the boilers on the surface; the steam from the boilers being conveyed down the shaft or pit by cast iron pipes, and the exhaust steam being also conveyed to bank up the pit in the same manner. The pit is what is called a *downcast* shaft, namely, the air for the ventilation of the mine being conveyed down the shaft.

The construction of the engine is, what is called a self-contained engine, the whole of the machinery being placed upon bed plates, rendering it capable of being readily removed from place to place, and taking up as little space as possible, both of which are essential requisites in such applications of power. Two cylinders are used, and likewise a fly-wheel, steadiness of action being extremely desirable in such cases, especially where wire ropes are used.

Two sets of rope rolls, AB, CD, are used in this case, all of which are capable of being attached or detached in, or out of gear—to run freely round upon the axles when the rope is dragged out from the engine, and to be attached to the axles when the power of the engine is applied to drag the train of tubs up, or along the plane. It is not necessary to give any detailed description of the machinery, as this will be sufficiently

comprehended from the drawings, and from the well-known mode of construction of such engines.

Figs. X., XI., and XII., *Plate I.*, show the ground plan, and sections of the planes on which this engine is applied. One set of rolls, say C and D, drags the loaded and empty carriages back and forwards on the plane Fig. X., and sect. Fig. XI., suppose between the Howlish landing and the landing near the pit; and the other set of rolls, A and B, drags them along the plane Fig. X, and section Fig. XII., suppose between the Woodside plane landing and the pit. One roll of each set being alternately thrown in, and out of gear, as the loaded trains are drawn towards, and the empty trains from, the engine.

This operation is thus performed. Sheaves, a and b, are placed at the ends of the planes, and besides the two ropes attached to the two rolls, what is called a tail rope passes round these sheaves, namely, a rope of the same length of the plane, one end of which is attached to the end of the loaded train, when the train is at the end next the sheave; and the other end is attached to the empty train at the landing near the shaft. When the engine therefore drags the loaded set towards the shaft it drags the tail-rope with it, and the other end being attached to the empty train of the other roll, it also drags the empty train, and with it the rope out from off the roll. When, therefore, the loaded train arrives at the landing near the pit, the empty train arrives at the end of the plane next the sheave. The gearing of the rolls is then changed, and the same operation alternately goes on throughout the day. This arrangement requires a double line of railway, or three rails, with a passing place in the middle between the pit and the landings.

Sometimes, however, where a great quantity of coals is not required to be conveyed, and a single line only is laid down (and this is the case in this instance), the rope from one of the rolls leads along the middle of the road, and is called the *main rope*, and the rope from the other roll leads along the side of the road, and is called the *tail rope;* this latter rope passes round the sheave at the end of the plane, and is attached alternately to the end of the loaded and the end of the empty set. Suppose the loaded set at the landing next the sheave, the main rope is attached to the one end of the train, and the end of the tail rope to the other—the train is then drawn to the landing next the shaft, by which process it drags after it the tail rope from off the other roll. The tail rope is then attached to the end of the empty set, and the end of the main rope to the other; the main roll is thrown out of, and the roll of the tail rope

into gear, and the empty set is thus drawn to the extreme end of the plane, or to any of the intermediate landings, by the tail rope which passes round the sheave.

Plate IV., Figs. I., II., and III., shows a Ground Plan, Front Elevation, and End View of an engine with an endless rope; Fig. I. being a ground plan, Fig. II. a front elevation, and Fig. III. an end view. The construction of the engine itself is the same as in *Plate III.*, with two horizontal cylinders, and attached to a bed plate, but the application of the rope rolls is entirely different—a, is the driving pinion on the crank axle, which works into the cog wheel b; on the same shaft, and fixed thereto, is a wheel c, with three grooves, as shown in the drawing—and d, is a similar grooved wheel—g, is a horizontal sheave, round which the rope passes, and which moves upon wheels, as shown, and h, is a vertical sheave, over which a rope passes, one end of which is attached to the framework of the moveable wheel g, and the other to a heavy weight w, and at the end of the plane another horizontal sheave is placed, round which the rope winds.

Figs. VII. and VIII., *Plate I.*, shows the plan and section of the plane which this engine works, and Fig. IX. shows the arrangement at and about the pit where the engine is placed.

The mode of operation is as follows:—The rope is an endless one; it passes three times round the grooved wheel c, worked by the engine, and the same number of times round the grooved wheel d. The darts show the direction which the rope runs. Passing along in the direction of the dart 1, it passes over the upper side of the wheel c, in the groove 3, to the underside, and over the groove 4, of the wheel d, then over and under grooves 5, and 7, and under and over 6, and 8, and from the upper side of 8, in the direction of the dart 9, around the sheave g, and so along the plane in the direction of dart 2, to the sheave s, shown in Fig. VII., *Plate I.*

The ropes always pass in the same direction, the loaded train being attached to the rope, dart 1, and the empty train to the rope, dart 2. It will therefore be seen that the action of the engine is always direct with the rope 1, and the loaded train; and the rope is prevented surging by passing round the three grooves on each of the wheels c, and d, and from them around the stretching wheel g, which, being attached to the weight w, keeps the rope always tight around the grooved wheels, and along the plane.

FRICTION OF ROPES ON FIXED ENGINE PLANES.

It is necessary, before going into the elucidation of the power and capabilities of fixed engines, to know the amount of friction of ropes on fixed engine planes, especially when the empty tubs are to take the rope down the plane, which rope is again to be used for dragging the loaded tubs up the plane; as this determines the limits of the employment of engines of the description of No. 1. And, as the employment of a sheave at the bottom or end of the plane, with a tail or endless rope, is attended with a good deal of friction; and, consequently, requires a greater amount of steam power, it is necessary to ascertain on what inclination of plane, and with what a number of tubs the rope can be taken out from the engine.

The theory for fixed engine planes is the same as that for the self-acting plane, except that there is no return set of tubs and rope to drag up the plane. Retaining the same notation as heretofore, we have

$$G' = G - \overline{F + n} = \frac{(w + w') \times s}{r t^2} \quad (1)$$

$$s = \frac{G - \overline{F + n}}{w + w'} \times r t^2 \quad (2)$$

$$t = \sqrt{\frac{(w + w') \times s}{G - \overline{F + n}}} \quad (3)$$

$$\text{And } \sin I = \frac{\frac{(w + w') \times s}{r t^2} + \overline{F + n}}{w} \quad (4)$$

The following are some experiments made for the purpose of ascertaining the amount of friction of the rope, rope wheel, and sheaves, or the value of n.

No. 1.—*EXPERIMENTS made on the Engine Plane at Eppleton Colliery, on the Friction of the Rope, Rope Wheel, and Sheaves.—March,* 1855.

Number of Experiment.	Number of Empty Tubs.	Time of Descent.	Distance traversed by Tubs.	Total Descent.	Inclination per Yard.	Rate of Inclination.	Weight of Tubs.	OBSERVATIONS.
		Min. Sec.	Feet.	Feet.	Inches.		lbs.	
1	6	2 — 35	1327·2	103·1	2·79	1 in 12·9	2778	Set Stopped.
2	5	3 — 40	1122·	94·5	3·03	1 .. 11·85	2315	Ditto.
3	5	2 — 45	1219·2	99·7	2·9	1 .. 12·23	2315	Ditto.
4	5	2 — 50	1167·	97·4	3·	1 .. 12·	2315	Ditto.
Average.	5	2 — 45	1169·4	97·2	3·	1 in 12·02	2315	

The size of rope was 3 inches in circumference, weight 3·75 lbs. per yard, being a wire rope. The rollers on which the rope runs upon the plane are 14 in. in length, 3½ in. in diameter, and the axles ⅞ in. in diameter—weight 32 lbs. They are placed 8 yards apart. Diameter of rope roll of engine 8 ft. 5 in., diameter of axle 9½ in. Weight of rope roll 4 tons. The plane on which these experiments were made is shown in Figs. II. and III., *Plate II.* In all these cases the train of tubs came to rest. The number of tubs usually run down at a time when in working is 21; but they do more than overhaul the rope, as the brake is obliged to be used. In these experiments the trains were set in motion from the top of the plane, the whole of the rope being upon the rope rolls, and the distance traversed was from the top of the plane.

In this experiment the length of rope was 390 yards, weight 1462·5 lbs.; the weight of rope roll, axle, &c., 4 tons; of rope upon the roll, 5910 lbs.; of sheaves or rollers, 1615 lbs. The moving power was $\frac{2315}{12} = 193$ lbs.; and supposing the friction of the tubs the 1-82nd part of the weight= $\frac{2315}{82} = 28$ lbs., and $193 - 28 = 165$ lbs. the moving power, which dragged the rope 390 yards in 2 min. 45 sec.

No. 2.—EXPERIMENTS made on the Friction of the Rope on the Engine Bank, Eppleton Colliery.—May 10th, 1855.

Number of Experiment.	Number of Empty Tubs.	Time.	Distance traversed by Tubs.	Length of Rope on Plane when the Set Started.	Total Length of Rope on Plane.	Total Fall.	Ratio of Inclination.	Weight of Tubs.	Distance from bottom of Plane to where Set stopped.	OBSERVATIONS.
		Min. Sec.	Yards.	Yards.	Yards.	In.		lbs.	Yards.	
1	29	4 — 5	654	1101	1755	946	1 in 25·10	13427	200	Stopped.
2	35	4 — 30	379	1548	1927	471	1 .. 28·80	16205	28	Joined the Set at the bottom.
3	35	5 — 0	389	1544	1933	485	1 .. 28·80	16205	22	Stopped.
4	39	3 — 45	393	1562	1955	498	1 .. 28·4	18057	....	Joined the Set at the bottom.
5	35	3 — 35	468	1487	1955	602	1 .. 28·12	16205	....	Stopped.

This experiment was made upon the same plane as the preceding, but it was commenced with the quantity of rope given in the fifth column on the plane before the train was put in motion, and the experiment was performed in this manner; the number of tubs given in the second column was attached to the rope, the brake was removed, and the set put in motion; the 4th column shows the distance which the gravity of the tubs dragged the rope before they came to rest. In the 4th experiment the set run into the landing.

In this experiment the length of the rope was 1955 yards, weight 7331 lbs., the weight of the rope rolls, &c., 4 tons, the weight of the sheaves 9192 lbs., (there being in the 1955 yards, 270 rollers 32 lbs. each, and 23 sheaves 24 lbs. weight each).

The moving power was, in the 4th experiment, $\frac{18{\cdot}057}{28{\cdot}34} = 637$ lbs., the friction $\frac{18{\cdot}057}{82} = 220$ lbs., and $637 - 220 = 417$ lbs., the moving power which dragged the rope 1955 yards in length, 393 yards in 3 minutes 45 seconds; and taking the 5th experiment would be 375 lbs. in 3 minutes 35 seconds, but in this case the train stopped, therefore the power was barely sufficient to drag the rope to the end of the plane.

No. 3.—*EXPERIMENTS made on an Engine Plane in the Minor East Pit at Hetton Colliery.—March,* 1855.

Number of Experiment.	Number of Tubs.	Time of Descent.	Distance traversed by Tubs.	Total Descent.	Inclination per Yard.	Rate of Inclination.	Weight of Tubs.	OBSERVATIONS.
		Min. Sec.	Feet.	Feet.	Inches.		lbs.	
1	19	0 — 44	83·7	5·15	2·20	1 in 16·4	9329	Set stopped.
2	20	1 — 9	105·6	6·22	2·09	1 .. 17·2	9830	Ditto.
3	21	3 — 57	777·	39·34	1·82	1 .. 19·8	10311	Ditto.
4	22	3 — 11	881·1	44·05	1·83	1 .. 19·7	10802	Ditto.
5	23	2 — 55	1165·5	58·63	1·80	1 .. 20·	11294	Set ran into landing.

The plane on which these experiments were made is shown in Figs. V. and VI., *Plate II.* The engine is placed near the shaft at a, the rope is taken along the horizontal part of the plane from a, to d, and the empty tubs passing down the plane from a, to C, overhauls the rope from a, to b, as well as down the plane from d, to C. The length of rope from a, to d, = 2838 feet, is therefore to be added to the length from d, to C, viz., 1165 feet, to determine the whole amount of friction. The rope was 2½ inches circumference, weight 2¼ lbs. per yard, length 1334 yards. There are 60 rollers on which the rope runs from a, to d, 3½ inches diameter, axles ⅞ inch diameter, weight 24 lbs., and there are 35 sheaves 9½ inches diameter, axles ⅞ inch, weight 24 lbs. The rollers whereon the rope runs from d, to C, are 10 inches long, 3½ inches diameter, axles ⅞ inches diameter, weight 24 lbs., 53 in number. There are 7 drums at the curve 18 inches diameter, axles 2 inches diameter, and weight 407 lbs. The diameter of the rope wheel of the engine is 4 feet 6 inches, the axle 4·25 inches, weight 4480 lbs. The number of tubs usually run at a time is 24, which requires the brake to be used.

In this experiment the length of the rope was 1334 yards, weight 3002 lbs., weight of the rope rolls 4480 lbs., of the sheaves and rollers 3559 lbs. The moving power in the 5th experiment was $\frac{11·294}{20}$ = 564·7 lbs., and the friction $\frac{11·294}{60}$ = 188 lbs. Then 564 — 188 = 376 lbs., the moving power which dragged the rope, 1334 yards in length, 390 yards, in 2 minutes 55 seconds.

No. 4.—EXPERIMENT at Killingworth on the Friction of the Rope of a Fixed Engine.—April, 1855.

In this case the engine is on the surface, and the rope is taken down the shaft. It passes over a sheave 8 feet in diameter at the top of the pit, it is then taken down the pit, 350 yards deep, then passes around a sheave 5 feet 5 inches diameter at the bottom of the pit, and then along a drift, nearly level, 923 yards in length, to the top of the engine plane. The gravity of the empty tubs down this plane drags the rope along the level and down the plane, 30 being run at a time, and the engine drags the loaded tubs up the plane.

Practically the weight of the rope in the shaft overhauls the rope from off the rope-roll of the engine, the brake having to be applied to prevent it from over-running at the bottom. The resistance to the gravitation of the tubs is therefore, the friction of the rope and sheaves along the level road, and upon the engine plane.

The circumference of the rope is 3⅝ths inches, weight per yard 5½ lbs. There are 25 ordinary rollers on flat, 5 inches diameter, axles ¾ inch, weight 30 lbs. each, and 86 sheaves 7 inches diameter, axles ¾ inch, weight 25 lbs.; and on the engine plane 84 ordinary rollers 30 lbs. each, and 5 friction sheaves 11 inches diameter, axles 1 inch. The length of the plane being 1048 feet. The rope is, therefore, 2770 + 1048 = 3818 feet, or 1273 yards × 5½ = 7001 lbs. weight, and the weight of the sheaves 5545 lbs. It is found that 6 empty tubs overhauls the rope, and will take it to the bottom of the engine plane; the weight of the tubs being 2777·4 lbs., and the plane 1 in 5·485. The gravity, therefore, is $2777{\cdot}4 \times \frac{1}{5{\cdot}485} = 506{\cdot}3$ lbs., from which deduct the friction, which has been previously found to be $\frac{1}{82}$nd part of the weight = 33·87 lbs., consequently the power required to overhaul the rope was 472·43 lbs.

The following Table will show the result of the foregoing Experiments.

Number of Experiment.	Total Moving Power.	Friction of Carriages.	Friction of Rope and Sheaves.	Length of Rope.	Weight of Rope.	Weight of Sheaves.	Weight of Rope Roll.
	lbs.	lbs.	lbs.	Yards.	lbs.	lbs.	lbs.
1	165	54	111	390	1462	1615	8960
2	637	220	417	1955	7331	9192	8960
3	564	188	376	1334	3002	3559	4480
4	506	34	472	1273	7001	5545	6720

Taking the aggregate result of these experiments, we find the total moving power of the 4 experiments to be 1376 lbs, the total weight of rope 18·806 lbs., making the moving power equal to $\frac{1}{13\cdot6}$th part of the weight of the rope; and the weight of the sheaves being 19·911 lbs.; the moving power is equal to the $\frac{1}{14\cdot4}$th part of their weight; and the weight of the rope and sheaves together being 38·707 lbs., and the moving power 1376 lbs. = $\frac{1}{28}$. It appears therefore that, when the moving power is equal to the $\frac{1}{28}$th part of the weight, it will drag the rope over sheaves and rollers similar to those used in the experiments, at an average speed of about five miles an hour.

I have not gone into the theoretical calculation of what part of the moving power was due to the production of the descent of the trains in the times given by the experiments, and so to determine the statical amount of friction. The practical utility of these experiments is intended to show what power, in the everyday application of such planes is required to produce a certain effect in a given time, the dynamical result being what is required.

It would appear, from these experiments, therefore, that with 35 tubs, a length of plane may be worked nearly 2000 yards in length, at an inclination of 1 in 28, without having recourse to a tail rope. If it be not convenient or advisable to work with such a number of tubs, then recourse must be had to a tail rope, or the line of the plane must be made at a greater inclination.

We have previously seen, that with self-acting planes an inclination of 1 in 30, appeared to be the limit to which this description of motive power could be extended; these experiments appear to show that an inclination of 1 in 28, is the limit to which engine planes can be extended, where the empty tubs have to drag the rope after them; beyond which it becomes necessary to resort to the use of a tail rope, and engine power to extend the system of underground transit.

In arriving at the above result, I have not taken into consideration the gravity of the rope upon the plane, which, to a certain extent, would increase the moving power. In the two first cases the entire length of rope was upon the descending plane, and therefore the gravitating force would be represented by sin I $\times$ $\frac{1}{2}$ weight of the rope. But in the two latter cases only a portion of the rope was upon the plane, the other portion being on the level part of the road, the former portion only in these cases must therefore be taken into the calculation. If the gravitation of the rope in these experiments is added, the aggregate resistance would be increased 380 lbs., and, consequently, the friction would be equal to the $\frac{1}{21\cdot3}$ part of the weight.

FIXED STEAM ENGINES.

I shall now give the details of the experiments made, for the purpose of ascertaining the power and capabilities of the different descriptions of engines, applied to the various kinds of planes, heretofore alluded to.

1. *Experiments on Engines dragging coals from the dip with a single rope.*

1. Hetton Colliery. *Engine in Eppleton Pit.*

This is a common high-pressure beam engine, with one cylinder thirty inches diameter, five feet stroke, on first motion with two rope rolls, similar to 1, 2, *Plate III.*, which are alternately put in and out of gear. The total length of the plane at present is 5865 feet, with an average inclination of 1 in 19·65. There are two boilers, each six feet diameter, and thirty feet long. The engine is placed underground; the rope rolls in a line with the plane. The distance from the boilers to the cylinder is 176 feet, requiring that length of steam pipe, which is 7¼ inches diameter. The steam from the cylinder is discharged into the flues by a pipe 86 feet in length and 7½ inches diameter.

The plan and section of the plane are given in Figs. I. and II., *Plate II.* It will be seen that there are three rails above the meetings and two below, and that there are several landings or points from whence the coals are brought by the engine. The mode of working this plane is as follows:—While the engine is dragging up the loaded set by one roll, the other roll is put out of gear, and the empty train is run down to the meetings, and immediately the loaded train passes, the empty train is run down to the landing, where another train of loaded tubs are ready, so that immediately one loaded set is drawn to the top of the plane, the other roll is thrown into gear, and another loaded set started from the bottom.

The rolls whereon the rope winds are each 8 feet 5 inches in diameter when empty, and when all the rope is on 9 feet 3 inches, the mean diameter being 8 feet 10 inches. The diameter of the axle is 9½ inches. Their weight is 4 tons. The rope is 3 inches in circumference, and 3¾ lbs. per yard in weight. The total length of rope is 2000 yards. The rope runs upon rollers, placed in the middle of the railway, 14 inches in length, 3½ inches in diameter; the axle ⅞ in. diameter, and 32 lbs. weight each. They are placed about 8 yards apart, and there are 270 of such rollers on the plane, with 23 rollers 10 inches long, 3½ inches diameter, axles ⅞ inch diameter, and 24 lbs. weight.

This engine has been erected some years, otherwise I should have preferred two cylinders.

No. 1.—*EXPERIMENT made on the Performance of the Fixed Engine at the Eppleton Pit, Hetton Colliery.—March,* 1855.

No. of Experiment.	No. of loaded Tubs.	Time of Experiment.	Pressure of Steam per Square Inch, in			Length of Plane.	Total Descent of Plane.	Inclination of Plane.	Weight of loaded Tubs.	OBSERVAT.
			Boiler.	Steam Chest.	Exhaust Pipe.					
		H. M.	lbs.	lbs.	lbs.	Feet.	Feet.			
1	21	11·53	41·5	42·5	..	3531	213·8	1 in 16·52	30,520	From the 3rd south way.
		·54	41·	34·	5·					
		·55	39·	37·	5·					
		·56	38·5	36·	5·					
		·57	36·	39·5	8·					158 double strokes of Engine.
		·58	35·	38·5	8·					
		·59	34·	37·	7·5					
		·59½	36·	36·5	7·5					
2	21	12·8	44·	45·	..	1760	..	1 in 16·	31,421	From the 1st north way.
		·9	41·	38·	7·					
		·10	41·	43·	7·					80 double strokes of Engine.
		·11	39·	40·	7·					
3	21	12·20	44·	46·	..	2709	167·3	1 in 16·19	30,826	From the 2d South way.
		·21	43·	38·	8·					
		·22	42·5	40·	8·					124 double strokes of Engine.
		·23	42·	42·	8·					
		·24	40·	40·5	8·					
		·25	37·	39·	8·					
4	21	12·38	44·	46·5	..	5865	298·5	1 in 19·65	30,681	From the 5th south way.
		·39	43·5	38·	8·					
		·40	42·	43·	8·					
		·41	41·	41·	8·					
		·42	39·	39·	8·					272 double strokes of Engine.
		·43	38·	38·	8·					
		·44	37·	37·	8·					
		·45	35·	36·	8·					
		·46	33·	34·	8·					
5	21	1·51	32·	30·5	..	3531	213·8	1 in 16·52	31,290	From the 3rd south way.
		·52	32·	28·	4·					
		·53	31·	31·75	4·5					
		·54	31·	31·5	5·					
		·55	30·	30·5	7·5					158 double strokes of Engine.
		·56	29·	29·5	..					
		·56⅓	29·	29·	..					
6	21	2·4	37·	36·5	..	5865	298·5	1 in 19·65	31,010	From the 5th south way.
		·5	36·	36·	5					
		·6	35·	36·	6·					
		·7	35·	35·	7·					
		·8	34·	34·	7·					272 double strokes of Engine.
		·9	33·	33.	7·					
		·10	32·	31·5	7·					
		·11	31·	31·	7·					
		·12	31·	30·	7·					
		·13	30·	29·	7·					
		·13⅓	29·	29·	7·					

No. 1 Experiments continued.

No. of Experiment.	No. of loaded Tubs.	Time of Experiment.	Pressure of Steam per Square Inch, in			Length of Plane.	Total Descent of Plane.	Inclination of Plane.	Weight of loaded Tubs.	OBSERVAT.
			Boiler.	Steam Chest.	Exhaust Pipe.					
		H. M.	lbs.	lbs.	lbs.	Feet.	Feet.		lbs.	
7	21	2·21	37·	37·	..	2709	167·3	1 in 16·19	31,479	From the 2d south way. 124 double strokes of Engine.
		·22	36·5	29·	3·					
		·23	35·	37·	6·					
		·24	35·	35·	7·					
		·25	34·	34·	7·					
8	21	2·47	45·	46·	..	3531	21·38	1 in 16·52	30,905	From the 3d south way. 158 double strokes of Engine.
		·48	44·5	41·	4·					
		·49	42·	44·	5·					
		·50	42·	42·	6·					
		·51	40·	41·	7·					
		·52	38·	39·	8·					
		·53	37·	36·5	6·					

Table I, of the results of the foregoing Experiments.

POWER.								
Number of Experiment.	Diameter of Cylinder	Area of Piston.	Pressure of Steam per Exper.	Total Amount of Power in pounds.	Length of Stroke of Piston.	No. of Strokes per Exper.	Space passed over in feet.	Total Amount of Power in pounds, moved one foot.
	Inches.	Cubic In.	lbs.		Feet.			
1	30	706·86	37·	26153·8	5	316	1580	41,323,035
2	..	....	41·5	29334·6	..	160	800	23,467,705
3	..	....	41·	28981·2	..	248	1244	36,052,691
4	..	....	39·2	27708·9	..	544	2720	75,368,200
5	..	....	30·	21206·	..	316	1580	33,505,100
6	..	....	32·8	23185·	..	544	2720	63,063,200
7	..	....	34·4	24316·	..	248	1244	30,249,080
8	..	....	41·2	29122·6	..	316	1580	46,013,700

RESISTANCE.							
Number of Experiment.	Gravity of Lead.	Friction of Carriages.	Friction of Rope, Sheaves, &c.	Gravity of Rope.	Total Amount of Resistance in pounds.	Space passed over in feet.	Total Amount of Resistance in pounds, moved one foot.
	lbs.	lbs.	lbs.	lbs.			
1	1847·3	372·2	328·72	55·71	2603·93	3531	9,194,476
2	1963·8	383·2	163·66	28·64	2539·30	1760	4,469,168
3	1904·	375·9	252·2	43·61	2575·71	2709	6,977,600
4	1561·3	374·2	546·0	77·80	2559·30	5865	15,010,280
5	1889·2	380·6	328·72	55·71	2654·23	3531	9,372,071
6	1578·1	376·9	546·0	77·80	2578·80	5865	15,124,680
7	1944·3	378·1	252·2	43·61	2618·21	2709	7,092,732
8	1870·7	383·9	328·72	55·71	2639·03	3531	9,318,417

The general performance of this engine is equal to 22 per cent., but it will be observed that the pressure on the exhaust pipe was about 7°, the average pressure of the steam 37°, therefore 37° − 7° = 30°; and as 30° : 37° :: 22 : 27 per cent. But it must also be remarked that the plane is not uniform, and that though the average inclination is 1 in 19·65, in one portion near the top, as will be seen by the section, the inclination is 1 in 9. Taking No. 6 Experiment this would give a performance of 39·5 per cent. on that part of the plane, which added to 5 per cent. for exhaust steam, gives 44·5 per cent. On this part of the plane, likewise, the diameter of the rope roll is the largest, as almost all the rope is upon it; and it should also be observed that the pressure of steam at that part of the experiment was below the average; the actual efficient performance in this part of the experiment would, therefore, be about 50 per cent. of the pressure of steam on the piston.

Killingworth Engine.

This is a common beam high pressure engine, having been formerly used for drawing coals. It is placed on the surface, and the rope is taken down the pit, 175 fathoms deep, then along a nearly horizontal piece of road about 800 yards in length, and then used for dragging the tubs up the plane. The cylinder is 25 inches diameter, 5 feet length of stroke. On second motion, driving wheel 4 feet diameter, and wheel on rope roll

8 feet 4 inches. The plane is single, therefore only one rope roll is used, 9 feet diameter, at starting, and 9 feet 4 inches when the rope is upon it. There are two boilers, each 6½ feet diameter, 23 feet long, with hemispherical ends. Length of fire grate 4 feet 8 inches, width 4 feet 6 inches. The boilers are placed near the cylinder, the steam pipe being 38 feet in length, 6 inches diameter.

The plane is a single line 1,048 feet in length, with an inclination of 1 in 5·485. The rope wheel being thrown out of gear, the empty tubs overhaul the rope to the bottom of the plane.

The dimensions of the rope roll, sheaves, and all the particulars regarding the resistance of the rope, is given in the No. 3 Experiment on the friction of ropes.

No. 2.—EXPERIMENT made on the performance of a Fixed Engine at Killingworth.—April, 1855.

No. of Experiment.	No. of loaded tubs	Time of Experiment.		Pressure of Steam per Square Inch in Boiler.	Length of Plane.	Descent of Plane.	Inclination of Plane.	Weight of loaded Tubs.	OBSERVATIONS.
		Min.	Sec.	lbs.	Feet.	Feet.		lbs.	
1	30	1	30	47·	1048	192·3	1 in 5·485	36,290	From landing extreme south way.
		1	0	46·5					
		1	30	45·5					
		2	0	44·5					74 double strokes of engine.
		2	30	43·5					
		3	0	42·5					
		3	30	42·					

Table II, of the Results of the foregoing Experiments.

POWER.								
No. of Experiment.	Diameter of Cylinder.	Area of Piston.	Pressure of Steam per Experiment.	Total Amount of Power in lbs.	Length of Stroke of Piston.	Number of Strokes per Experiment.	Space passed over in Feet.	Total Amount of Power, in Pounds, Moved One Foot.
	Inches.	Sqr. Inc.	lbs.		Feet.			
1	25	490·875	44·5	21844·	5	148	740	16,164,560

RESISTANCE.							
Number of Experiment.	Gravity of Load.	Friction of Carriages.	Friction of Rope, Sheaves, &c.	Gravity of Rope.	Total Amount of Resistance in lbs.	Space passed over in Feet.	Total Amount of Resistance in Pounds, Moved One Foot.
	lbs.	lbs.	lbs.	lbs.			
1	6618·	442·6	448·	351·	7859·6	1048	8,236,860

The performance here is nearly 50 per cent. of the moving power. The engine being placed at bank there will be no deduction for the exhaust pipe, and the plane being uniform, the above may be considered the maximum performance.

Springwell Engine.

This engine is also a common beam engine, placed underground, the rolls in a line with the plane. The cylinder is 22 inches diameter, length of stroke 4 feet. On second motion, the diameter of the driving wheel being 2 feet 8 inches, and of the wheel on the rope roll 5 feet 2 inches. There are 2 boilers, each 6 feet 1 inch diameter, and 16 feet 4 inches in length; length of fire-grate 4 feet 8 inches, width 3 feet 8 inches. The boilers are placed near the cylinder, requiring only 20 feet 6 inches of steam pipe, 5½ inches in diameter. The steam is discharged into a small pit, by pipes, 30 feet 6 inches in length and 6 inches diameter.

The plane is a single line of railway, 4890 feet in length, with an average inclination of 1 in 15. The rope wheel being thrown out of gear when the loaded set reaches the top, the empty tubs run down and drag the rope after them. There are several landings from whence the coals are brought up the plane.

The rolls whereon the rope winds is 7 feet diameter at starting, and 7 feet 6 inches diameter when all the rope is upon the roll; the axle is 8½ inches, weight 3920 lbs; rope 2¾ inches circumference, and weight 3¼ lbs per yard; the total length 1630 yards. The rope runs upon rollers 14 inches in length, 4 inches diameter; the axles ⅞ inch diameter, and the weight 28 lbs each; they are placed 9 yards apart, there being 180 upon the plane.

No. 3.—*EXPERIMENTS made on the performance of a Fixed Engine at Springwell Colliery.—April,* 1855.

No. of Experiment.	No. of Loaded Tubs.	Time of Experiment.	Pressure of Steam per Square Inch at Boiler.	Length of Plane.	Descent of Plane.	Inclination of Plane.	Weight of Loaded Tubs.	OBSERVATIONS.
		Min. Sec.	lbs.	Feet.	Feet.		lbs.	
		commenc't.	28·					
1	24	1 0	27·	4612	333	1 in 14·3	30,912	From Russell's south way.
		2 0	25·5					
		3 0	24·5					
		4 0	24·					398½ double strokes of Engine.
		5 0	23·					
		6 0	23·					
		7 0	22·					
		8 0	22·					
		9 0	21·5					
2	24	commenc't.	28·5					
		1 0	28·	4612	333	1 in 14·3	30,912	From Russell's south way.
		2 0	26·					
		3 0	25·					
		4 0	24·5					398½ double strokes of Engine.
		5 0	23·5					
		6 0	23·					
		7 0	22·5					
		8 0	22.					
		9 0	21·5					
3	24	commenc't.	28·5	5335	375·3	1 in 13·85	30,912	From Russell's extreme dip Drift.
		1 0	27·5					
		2 0	26·					
		3 0	24·5					456 double strokes of Engine.
		4 0	23·5					
		5 0	23·					
		6 0	22·					
		7 0	21·5					
		8 0	21·					
		9 0	20·5					
		9 30	20·					

Table III, of the results of the foregoing Experiments.

POWER.								
Number of Experiment.	Diameter of Cylinder	Area of Piston.	Pressure of Steam per Exper.	Total Amount of Power in pounds.	Length of Stroke of Piston.	No. of Strokes per Exper.	Space passed over in feet.	Total Amount of Power in pounds, moved one foot.
	Inches.	Sqr. Inc.	lbs.		Feet.			
1	22	380·	24·	9120	4	797	3188	29,074,560
2	..	....	24·5	9310	..	797	3188	29,680,280
3	..	....	23·5	8930	..	912	3648	32,576,640

RESISTANCE.							
Number of Experiment.	Gravity of Load.	Friction of Carriages.	Friction of Ropes, Sheaves, &c.	Gravity of Rope.	Total Amount of Resistance in pounds.	Space passed over in feet.	Total Amount of Resistance in pounds, moved one foot.
	lbs.	lbs.	lbs.	lbs.			
1	2216·	386·4	369·	370·	3341·4	4612	15,410,536
2	2216·	386·4	369·	370·	3341·4	4612	15,410,536
3	2232·	386·4	369·	383·	3379·4	5335	17,981,084

The average performance of this engine is 53·4 per cent. of the pressure of the piston; and, if we take into account that the plane is not quite uniform, the maximum performance will be above 55 per cent.

No. 2.—EXPERIMENTS on Engines dragging Coals along Levels where Horses were formerly used.

ELEMORE ENGINE, HETTON COLLIERY.

This engine and the boiler is placed underground. The construction of the engine is the same as that shewn in Figs. I., II., and III., *Plate III.*, viz., with 2 cylinders placed horizontal on a bed plate; but there are only two rope rolls. The cylinders and engine are placed underneath the railway, the ropes being brought out to the level of the road. The cylinders are 12 inches in diameter each, 2 feet stroke. The rolls are on the second motion, driving wheel 2 feet 6 inches diameter, wheel on roll 4 feet 6 inches diameter. The diameter of roll at starting is 4 feet 6 inches, and when the rope is all on the roll 5 feet. One boiler 5 feet 4 inches diameter, and 31 feet long, with hemispherical ends. Fire grate 5 feet in length, 5 feet 6 inches in width. The engine is placed at a considerable distance from the boiler, the steam pipe being 313 feet in length and 5 inches diameter. But there is a steam receiver placed immediately over the cylinders, 56 cubic feet in area. The steam is exhausted into the furnace drift by two pipes, each 4 inches diameter, and 336 feet in length.

The plane has a double line of rails the entire distance, and the engine, by the two rope rolls, draws a loaded set of tubs out towards the shaft with one rope roll, and at the same time draws an empty set of tubs in the other direction by a tail rope passing around a sheave or wheel at the extreme end of the plane. The diameter of the rope rolls is 4 feet 6 inches, the axles 4¾ inches, weight 15 cwt. each; diameter of sheaves for tail

rope 4 feet, axle 2½ inches, weight 2 cwt. The two main ropes are 2⅝ inches circumference, weight 3 lbs per yard; wire tail rope 1¾ inches circumference, weight 1½ lbs per yard. The rollers on the straight line of way are 14 inches long and 3½ inches diameter, axles ⅞ inch in diameter; there are 260 on the two lines 32 lbs weight each, with 21 large drums and 25 small, weights respectively 407 lbs and 210 lbs, at the curves; diameter of former 18 inches, latter 12 inches, axles 2 inches.

The plan and section of this plane are given in Figs. VI. and VII., *Plate II.*, from which it will be seen that the plane has a considerable curve in it, and that it is by no means a favorable line for the application of a steam engine. It was originally a horse road, and was converted into an engine plane, and shows under what circumstances engine power can be applied. The section of the line, also, it will be seen is not at all uniform, but comprizes all the undulations which may fairly be deemed to be requisite to meet the ordinary undulations of the strata, and also that of a water level.

No. 4.—EXPERIMENTS made on the Fixed Engine at Elemore Colliery, with a Tail or double Rope.—March, 1855.

No. of Experiment.	Number of Tubs. Loaded.	Number of Tubs. Empty.	Time of Experiment.	Pressure of Steam per Square Inch, At Boiler.	Pressure of Steam per Square Inch, At Receiver	Length of Plane.	Descent of Plane.	Inclination of Plane.	Weight of Tubs. Loaded.	Weight of Tubs. Empty.	Observat.
			H. M.	lbs.	lbs.	Feet.	Feet.		lbs.	lbs.	
1	25	26	9·45	31·	31·25	3873	19·2	1 in 201·72	36,089	11,778	From end of Plane.
			·46	31·	29·25						
			·47	30·5	28·5						
			·48	30·5	28·75						470 double strokes of each Cylinder.
			·49	30·5	29·						
			·50	30·5	29·						
			·51	31·	31·25						
2	25	24	10·2	36·	36·25	3873	19·2	1 in 201·72	35,983	10,872	From end of Plane.
			·3	35·5	34·25						
			·4	35·	33·25						
			·5	34·	32·25						470 double strokes of each Cylinder.
			·6	33·5	31·25						
			·7	32·5	30·75						
			·7½	..	30·5						
			·8	32·	31·5						
3	25	24	10·19	35·5	35·25	3873	19·2	1 in 201·72	38,406	10,872	From end of Plane.
			·20	34·5	32·75						
			·21	33·5	31·75						
			·22	32·5	31·25						470 double strokes of each Cylinder.
			·23	32·	30·5						
			·24	31·	29·75						
			·24½	32·	31·5						
4	25	23	10·33	34·	34·	3873	19·2	1 in 201·72	35,801	10,419	From end of Plane.
			·34	33·5	32·75						
			·35	32·5	31·80						
			·36	32·	31·25						470 double strokes of each Cylinder.
			·37	31·5	30·25						
			·38	30·5	29·25						
			·39	29·5	28·5						
			·40	29·	28·5						
5	23	24	10·47	32·	32·	3873	19·2	1 in 201·72	32,935	10,872	From end of Plane.
			·48	32·	31·5						
			·49	32·5	31·75						
			·50	33·	32·20						470 double strokes of each Cylinder.
			·51	33·5	32·5						
			·52	33·5	32·75						
			·53	33·5	32·75						
			·54	33·25	32·9						
			·54¾	34.	34·						

No. 4 Experiments continued.

No. of Experiment.	Number of Tubs. Loaded.	Number of Tubs. Empty.	Time of Experiment.	Pressure of Steam per Square Inch, At Boiler.	Pressure of Steam per Square Inch, At Reserv.	Length of Plane.	Descent of Plane.	Inclination of Plane.	Weight of Tubs. Loaded.	Weight of Tubs. Empty.	Observat.
			H. M.	lbs.	lbs.	Feet.	Feet.		lbs.	lbs.	
6	25	25	11·4	35·25	35·25	3873	19·2	1 in 201·72	36,247	11,325	From end of Plane.
			·5	34·75	33·6						
			·6	33·5	32·75						470 double strokes of each Cylinder.
			·7	33·	31·75						
			·8	32·5	30·75						
			·9	31·75	30·25						
			·10	30·5	29·25						
			·10¾	30·5	30·						
7	24	24	11·18	33·	33·	3873	19·2	1 in 201·72	35,203	10,872	From end of Plane.
			·19	33·	31·75						
			·20	32·75	31·4						470 double strokes of each Cylinder.
			·21	32·5	31·						
			·22	32·25	31·5						
			·23	32·	31·						
			·24	31·5	30·5						
			·24½	31·5	32·						
8	24	24	12·25	33·5	32·25	3873	19·2	1 in 201·72	33,910	10,872	From end of Plane.
			·26	33·25	31·75						
			·27	32·5	31·						470 double strokes of each Cylinder.
			·28	32·	30·5						
			·29	31·5	30·						
			·30	31·	30·						
			·30¾	..	29·5						
			·31	30·	30·5						
9	24	25	12·41	33·25	33·5	3873	19·2	1 in 201·72	35,630	11,325	From end of Plane.
			·42	33·	32·75						
			·43	32·75	31·75						470 double strokes of each Cylinder.
			·44	32·	31·						
			·45	31·25	30·5						
			·46	30·5	29·75						
			·47	30·	29·						
			·48	29·5	28·80						
			·48½	29·5	29·25						
10	38	38	12·58	32·5	32·5	3873	19·2	1 in 201·72	54,976	17,214	From end of Plane.
			·59	32·	30·25						
			1·	31·	29·25						470 double strokes of each Cylinder.
			·1	30·	28·65						
			·2	29·25	28·						
			·3	29·	27·75						
			·4	28·5	28·25						

Table IV, of the Results of the foregoing Experiments.

POWER.								
Number of Experiment.	Diameter of each Cylinder.	Area of Two Pistons.	Pressure of Steam per Experiment.	Total Amount of Power in Pounds.	Length of Stroke of Piston.	No. of Strokes per Experiment.	Space passed over in Feet.	Total Amount of Power in Pounds, moved One Foot.
	Inches.	Sq. In.	lbs.	lbs.	Feet.			
1	12	226·19	29 5	6728·8	2	940	1880	12,544,785
2	..	....	32·5	7351·4	..	940	1880	13,820,540
3	..	....	31·8	7193·3	..	940	1880	13,522,860
4	..	....	30·4	6876·3	..	940	1880	12,927,510
5	..	....	32·5	7351·5	..	940	1880	13,820,540
6	..	....	31·7	7170·4	..	940	1880	13,480,330
7	..	....	31·5	7125·3	..	940	1880	13,395,300
8	..	....	30·7	6944·3	..	940	1880	13,055,100
9	..	....	30·7	6944·3	..	940	1880	13,055,100
10	..	....	29·2	6605·1	..	940	1880	12,417,200

RESISTANCE.							
Number of Experiment.	Gravity of Load.	Friction of Carriages.	Friction of Rope, Sheaves, &c.	Gravity of Rope.	Total Amount of Resistance in Pounds.	Space passed over in Feet.	Total Amount of Resistance in Pounds, moved One Foot.
	lbs.	lbs.	lbs.				
1	120·5	578·8	1128	....	1586·3	3873	6,143,740
2	124·5	566·6	1128	....	1570·1	3873	6,081,000
3	136·5	595·8	1128	....	1587·3	3873	6,146,450
4	125·9	558·9	1128	....	1561·	3873	6,144,000
5	109·4	529·7	1128	....	1548·3	3873	5,996,650
6	123·5	575·3	1128	....	1579·8	3873	6,118,565
7	120·6	557·1	1128	....	1564·5	3873	6,059,310
8	114·2	541·5	1128	....	1555·3	3873	6,023,700
9	120·4	567·8	1128	....	1575·4	3873	6,101,530
10	187·1	872·9	1128	....	1813·8	3873	7,024,846

The average effective performance is 45·8 per cent. of the pressure on the piston, but the last experiment is 56·5 per cent. The last experi-

ment was, however, made to ascertain the ultimate performance of the engine rather than the practical working result, therefore the former must be taken as the practical efficient performance. The gravitation has, however, been taken on the average of the entire length of the plane, whereas it will be seen by *Plate II*, Fig. VII, that it is not uniform, and this will give an increased performance of both loaded and empty trains, on the level part of the former, and on the greater inclination of the latter.

East Minor Pit Engine, Hetton Colliery.

This engine is similar in construction to the Elemore engine, both engine and boilers being underground, and having two cylinders placed, together with the rope rolls, on bed plates. The cylinders are 9 inches in diameter; length of stroke 2 feet. The rolls are on the second motion, the diameter of the driving wheel being 2½ feet diameter, and that on the rope wheel shaft 4½ feet diameter. The diameter of roll at starting is 4½ feet diameter; and when rope is on 5 feet 4 inches diameter. Two boilers each 5 feet 4 inches diameter, and 24 feet long, with hemispherical ends. These boilers, however, supply another engine. Length of fire grate 5 feet, and width 5 feet 4 inches. The engine is 139 feet from boilers, requiring 139 feet of pipe, 6 inches diameter. This engine has no steam receiver; the steam exhausts into upcast shaft 30 feet distant, with 5 inch pipe.

The plan and section of this plane is shown in Figs. IV and V, *Plate II.* It consists of a single line, with a double line where the loaded and empty trains pass. It was formerly a horse road, and the section, it will be seen, is not uniform. Coals are brought from different points, and likewise from another engine plane to the dip, of sufficient descent to drag a rope the whole length of this plane, and of the plane to the dip.

This plane is worked by a tail rope, which runs upon sheaves placed alongside the railway, and which passes around the wheel at the end of the plane, as shown in the plan. The diameter of the tail rope wheel is 4 feet, axle 2½ inches, weight 2½ cwts. The length of rope is three times that of the length of the plane, viz. 3,900 yards, wire, circumference 2½ in., weight per yard 3 lbs.; the tail rope being the same size as the main rope. The diameter of the tub wheels is 7·5 inches, diameter of axles 1·3775 inches; the same as No. 2 experiment, page 252. There are on the main road 122 rollers, 10 inches long, and 26, 14 inches long, both being 3½ inches diameter; diameter of axles ⅞ inch, the weight being respectively 24 lbs. and 32 lbs. And for the tail rope 140 rollers and 13 sheaves, diameter of former 3½ inches, and latter 9½ inches, diameter of axles ⅞ inch, weight of each 24 lbs.

No. 5.—EXPERIMENT made on the Fixed Engine with Tail Rope, East Minor Pit, Hetton Colliery.—March, 1855.

No. of Experiment.	Number of Tubs. Loaded.	Number of Tubs. Empty.	Time of Experiment.	Pressure of Steam per Square Inch. Boiler.	Pressure of Steam per Square Inch. Engine.	Length of Plane.	Descent of Plane.	Inclination of Plane.	Weight of Tubs. Loaded.	Weight of Tubs. Empty.	OBSERVAT.
			H. M.	lbs.	lbs.	Feet.	Feet.		lbs.	lbs.	
1	24	..	8·53	46·5	45.	1494	5·46	1 in 273·62	33,312	..	From first west inclined plane. 174 double strokes of each Cyl.
			·54	46·	44·5						
			·55	46·	44·5						
			·56	46·	45·						
			·56¾	47·	46·						
2	..	24	9·4	49·	44·75	3853·5	16·2	1 in 237·87	..	11,160	From 2nd west inclined Plane. 430 double strokes of each Cyl.
			·5	47·5	44·25						
			·6	46·	44·5						
			·7	45·5	44·						
			·8	45·	43·5						
			·9	44·5	43·5						
			·10	44·5	43·25						
			·11	44·5	43·5						
			·12	44·5	44.						
3	24	..	9·17	45.	44·	3853·5	16·2	1 in 237·87	33,312	..	From north inclined Plane. 410 double strokes of each Cyl.
			·18	44·5	43·25						
			·19	44·	43·						
			·20	43·	41·5						
			·21	42·	41·						
			·22	41·5	40·5						
			·23	42·	41·						
4	..	25	9·32	49·	48·25	3863·5	16·2	1 in 237·87	..	11,625	From north inclined Plane. 430 double strokes of each Cyl.
			·33	49·	47·75						
			·34	48·5	47·						
			·35	48·	47·						
			·36	48·	46·25						
			·37	47·5	46·						
			·38	47·	46·						
			·39	47·	46·25						
5	26	..	9·44	46·	45·	3863·5	16·2	1 in 237·87	36,088	..	From north inclined Plane. 410 double strokes of each Cyl.
			·45	46·	44·5						
			·46	45.5	44·						
			·47	45.	43·						
			·48	44·5	43·						
			·49	44·	43·25						
			·50	44·	43·75						
6	..	24	9·59	47·	45·5	2838	14·68	1 in 193·32	..	11,160	From Engine way to east. 330 double strokes of each Cyl.
			10·	46·	45·5						
			·1	45·5	43·75						
			·2	44·	43·						
			·3	44·	42·75						
			·4	43·5	42·5						
			·4½	43·5	43·						

No. 5 Experiment continued.

No. of Experiment.	Number of Tubs. Loaded.	Number of Tubs. Empty.	Time of Experiment.	Pressure of Steam per Square Inch, Boiler.	Pressure of Steam per Square Inch, Engine.	Length of Plane.	Descent of Plane.	Inclination of Plane.	Weight of Tubs. Loaded.	Weight of Tubs. Empty.	OBSERVAT.
			H. M.	lbs.	lbs.	Feet.	Feet.		lbs.	lbs.	
7	25	..	10·9	44·	43·5	2838	14·68	1 in 193·32	34,700	..	From Engine way to east. 300 double strokes of each Cyl. Could just bring set out.
			·10	44·	43·						
			·11	43·5	42·5						
			·12	42·	41·5						
			·13	41·	40·5						
			·14	41·	40·5						
			·15	41·5	41·25						
			·16	42·	41·5						
			·17	42·	42·						
8	..	24	10·23	48·	46·5	1494	5·46	1 in 273·62	..	11,160	From first west inclined Plane. 215 double strokes of each Cyl.
			·24	47·5	44·75						
			·25	46·	44·25						
			·26	44·5	43·25						
			·27	44·	43·						
			·27½	44·	43·						
9	23	..	10·31	45·5	43·	1494	5·46	1 in 273·62	31,924	..	From first west inclined Plane. 174 double strokes of each Cyl.
			·32	45·5	44·						
			·33	45·	43·5						
			·34	45·	44·						
			·33	44·5	43·5						
10	..	24	10·45	44·5	43·5	38525	16·2	1 in 237·87	..	11,160	From north inclined Plane. 430 double strokes of each Cyl.
			·46	44·	42·25						
			·47	44·	43·						
			·48	43·5	42·75						
			·49	43·5	42·25						
			·50	43·	42·						
			·51	42·5	41·5						
			·52	42·5	42·						

Table VI, of the Results of the foregoing Experiments.

POWER.								
Number of Experiment.	Diameter of each Cylinder	Area of Two Pistons.	Pressure of Steam per Experiment.	Total Amount of Power in Pounds.	Length of Stroke of Pistons.	No. of Strokes per Experiment.	Space passed over in Feet.	Total Amount of Power in Pounds moved One Foot.
	Inches.	Sq. In.	lbs.		Feet.			
1	9	147·23	45·	6625·5	2	348	696	4,611,244
2	..	....	43.8	6448·7	..	860	1720	11,091,715
3	..	....	42·	6183·6	..	820	1640	10,141,200
4	..	....	46·8	6390·4	..	860	1720	11,851,500
5	..	....	43 8	6448·7	..	820	1640	10,575,820
6	..	....	43·8	6448·7	..	660	1320	8,512,260
7	..	....	41·8	6154·2	..	600	1200	7,285,050
8	..	....	44·	6478·1	..	430	860	5,571,175
9	..	....	43·8	6448·7	..	378	696	4,488,276
10	..	....	42·4	6242·5	..	660	1320	8,240,180

RESISTANCE.							
Number of Experiment.	Gravity of Load.	Friction of Carriages.	Friction of Rope, Sheaves, &c.	Gravity of Rope.	Total Amount of Resistance in Pounds.	Space passed over in Feet.	Total Amount of Resistance in Pounds, moved One Foot.
	lbs.	lbs.	lbs.				
1	140·6	628·5	544·	....	1031·9	1494·	1,541,210
2	46·9	210·6	544·	....	801·5	3853·5	3,088,200
3	140·	628·5	544·	....	1032·5	3853·5	3,978,223
4	48·8	219·4	544·	....	812·2	3863·5	3,130,717
5	151·8	680·	544·	....	1062·2	3863·5	4,103,810
6	57·7	210·5	544·	....	812·2	2838·	2,305,024
7	179·5	655·	544·	....	1019·5	2838·	2,893,340
8	46·9	210·6	544·	....	801·5	1494·	1,197,440
9	134·3	602·3	544·	....	1012·	1494·	1,511,928
10	46·9	210·6	544·	....	801·5	3853·5	3,088,200

The efficient average performance of this engine is 33 per cent. of the pressure of steam on the piston, but the result, with the loaded carriages, is 37·8 per cent., and with the empty carriages 28·3 per cent. On examining the section it will be seen there is, for about 150 yards, an inclination of 1 in 100, which on that portion of the road would raise the performance to nearly 50 per cent., and with the empty carriages there is an inclination of 1 in 38 for about 90 yards, which raises the performances on that part of the road to 37 per cent.

Killingworth Engine.

This engine is of the same construction as the East Minor Pit, and the Black Boy engine, *Plate III*, having, however, only two rope rolls. Two cylinders 12 inches diameter each, 2 feet stroke. The engine is on the second motion, diameter of driving wheel 2 feet 3 inches, and of wheel on roll axle, 4 feet 6 inches. The diameter of the rope roll is 4 feet 6 inches at starting, and 5 feet when rope is on. The engine is placed at the bottom of the pit, 350 yards in depth, and the boilers at bank. There are 3 boilers, diameter 5 feet 1 inch, length 34 feet, including the hemispherical ends. Length of fire-grate 4 feet 8 inches, and width 4 feet. The boilers are 150 feet from the top of the pit, from which the steam is conveyed by pipes 10½ inches in diameter, then down the shaft 690 feet, and 36 feet to a receiver No. 1, with 10½ inch pipes. Then with 5 inch pipes from the receiver No. 1 to the shaft again, 36 feet; down the shaft 360 feet further, and 34 feet to receiver No. 2, and from thence 35 feet to the engine. The entire distance from the boilers to the cylinders being 1341 feet; which are 1050 feet below the level of the boilers. The reservoir No. 1 is 13 feet in length and 5 feet 2 inches diameter inside, and No. 2, 5 feet in length, and 3½ feet in diameter, exclusive of hemispherical ends. The pipes are wrapped with felt, 1 inch thick, and covered with asphalte. The exhaust steam is conveyed by 6-inch pipes from the engine up the shaft 360 feet and level 95 feet, and is then discharged into the shaft 690 feet from the surface. The steam pipes from the boilers passing down the latter shaft, the temperature is about 85°; but the small pipes from receiver No. 1 pass down the downcast shaft, up which water is drawn in tubs 12 hours in each day. A great condensation, as will hereafter be seen, takes place, the temperature near the pipes being 70° to 85°, and 44° in the other parts of the shaft, besides water continually dropping on the pipes.

The plane which this engine works is about 700 yards in length, there

being three points from whence the coals are brought. It is a single line, with a tail rope running on the side of the way. There is, therefore, one length of rope on each roll, and the tail rope or 2770 yards, circumference $2\frac{3}{8}$ inches, wire, $2\frac{1}{2}$ lbs. weight per yard. The diameter of the tail rope sheave is 5 feet 4 inches, axle $2\frac{1}{4}$ inches, weight 6 cwt. There are 112 rollers on the main road, 5 inches diameter, axles $\frac{3}{4}$ inch, weight 30 lbs. each; and there are 127 sheaves for tail rope, 7 inches diameter, axles $\frac{3}{4}$ inch, weight 25 lbs. each.

EXPERIMENTS made at the Fixed Engine at Killingworth Colliery.—April, 1855.

No. of Exper.	Number of Tubs.	Time of Experiment.	Pressure of Steam per Square Inch, in Boilers	Pressure of Steam per Square Inch, in Receiver No. I.	Pressure of Steam per Square Inch, in Receiver No. II.	Length of Plane.	Descent of Plane.	Inclination of Plane.	Weight of Tubs.	OBSERVAT.
		Mn. Sc.	lbs.	lbs.	lbs.	Feet.	Feet.		lbs.	
1	30	Comenc.	32·	32·	32·	1181·4	9·1	1 in 129·82	13,888	From Cross Cut way. 154 double strokes of Engine.
		0 30	32·	32·	31·75	Pressure of Steam at Exhaust Pipe, 3 lbs. ℔ sq. inch.				
	Empty	1 0	32·	31·5	29·75					
	Tubs.	1 30	32·	31·	31·					
		1 50	31·5	32·	32·					
2	28	Comenc.	33·	32·5	33·5	1181·4	9·1	1 in 129·82	33,362	From Cross Cut way. 154 double strokes of Engine.
		0 30	33·	32·5	32·75					
	Loaded	1 0	33·75	32·	31·					
	Tubs.	1 30	32·75	32·	30·5					
		1 50	33·	32·5	32·5					
3	30	Comenc.	34·25	34·	35·	1946·3	15·55	1 in 125·02	13,888	From Engine bank way. 229 double strokes of Engine.
		0 30	34·5	34·	34·	Pressure of Steam at Exhaust Pipe, 3 lbs. ℔ sq. inch.				
	Empty	1 0	34·	33·	33·					
	Tubs.	1 30	34·	33·	31·25					
		2 0	33·75	33·	31·					
		2 30	33·5	32·75	33·					
		2 37	33·5	33·	34·					
4	30	Comenc.	34·	33·	34·5	1946·3	15·55	1 in 125·02	36,232	From Engine bank way. 229 double strokes of Engine.
		0 30	33·5	33·	33·5					
	Loaded	1 0	33·5	32·5	32·75					
	Tubs.	1 30	33·	32·	30·75					
		2 0	32·75	32·5	30·25					
		2 30	32·75	33·	32·					
		2 40	....	....	33·					
5	30	Comenc.	33·	32·25	33·5	2178·	15·67	1 in 139·	13,888	From High Coal way. 278 double strokes of Engine.
		0 30	33·	32·5	32·5					
	Empty	1 0	32·75	32·	31·25					
	Tubs.	1 30	32·5	32·	30·5					
		2 0	32·	31·5	30·					
		2 30	32·	31·	30·5					
		3 0	31·75	31·	31·25					
6	30	Comenc.	33·	32·25	33·5	2178·	15·67	1 in 139·	36,876	From High Coal way. 278 double strokes of Engine.
		0 30	33·	32·5	32·5	Pressure of Steam at Exhaust Pipe, 7 lbs. ℔ sq. inch.				
	Loaded	1 0	32·75	32·	31·25					
	Tubs.	1 30	32·5	32·	30·5					
		2 0	32·	31·5	30·					
		2 30	32·	31·	30·5					
		3 0	31·75	31·	31·25					
7	30	Comenc.	34·	34·	34·	1946·3	15·55	1 in 125·02	13,888	From Engine bank way. 229 double strokes of Engine.
		0 30	34·	34·	33·75					
	Empty	1 0	33·75	33·5	33·					
	Tubs.	1 30	33·5	33·	31·5					
		2 0	33·25	32·5	31·					
		2 30	33·	32·5	32·5					
		2 45	33·25	33·5	33·5					

Experiment continued.

No. of Exper.	No. of Tubs.	Time of Experiment.	Pressure of Steam per Square Inch, in			Length of Plane.	Descent of Plane.	Inclination of Plane.	Weight of Tubs.	OBSERVAT.
			Boilers	Receiver No. I.	Receiver No. II.					
		Mn. Sc.	lbs.	lbs.	lbs.	Feet.	Feet.		lbs.	
8	30	Comenc.	33·5	33·5	34·25	1946·3	15·55	1 in 125·02	35,280	From Engine bank way. 229 double strokes of Engine.
	Loaded Tubs.	0 30	33·5	33·	33·5	Pressure of Steam at Exhaust Pipe, 7 lbs. ⅌ sq. inch.				
		1 0	33·25	33·	32·25					
		1 30	33·	32·5	31·					
		2 0	32·75	32·	30·5					
		2 30	32·5	32·	32·					
		2 45	32·5	32·	33·					

Table VI, of the Results of the foregoing Experiments.

POWER.								
Number of Experiment.	Diameter of each Cylinder	Area of Two Pistons.	Pressure of Steam per Experiment.	Total Amount of Power in Pounds.	Length of Stroke of Pistons.	No. of Strokes per Experiment.	Space passed over in Feet.	Total Amount of Power in Pounds moved One Foot.
	Inches.	Sq. In.	lbs.		Feet.			
1	12	226·19	31·3	7079·7	2	308	616	4,360,600
2	..	....	32·	7238·	..	308	616	4,458,608
3	..	....	33·	7464·2	..	458	916	6,837,210
4	..	....	32·4	7328·5	..	458	916	6,712,905
5	..	....	31·2	7057·1	..	556	1112	7,847,500
6	..	....	31·2	7057·1	..	556	1112	7,847,500
7	..	....	32·7	7396·4	..	458	916	6,774,736
8	..	....	32·4	7328·5	..	458	916	6,712,905

RESISTANCE.							
Number of Experiment.	Gravity of Load.	Friction of Carriages.	Friction of Rope, Sheaves, &c.	Gravity of Rope.	Total Amount of Resistance in Pounds.	Space passed over in Feet.	Total Amount of Resistance in Pounds, moved One Foot.
	lbs.	lbs.	lbs.				
1	107·	170·	481·	....	758	1181·4	895,010
2	257·	407·	481·	....	631	1181·4	745,463
3	111·	170·	481·	....	762	1946·3	1,483,080
4	290·	442·	481·	....	633	1946·3	1,232,080
5	100·	170·	481·	....	751	2178·	1,635,680
6	265·	450·	481·	....	666	2178·	1,450,550
7	111·	170·	481·	....	762	1946·3	1,483,080
8	282·	430·	481·	....	629	1946·3	1,224,220

The average performance of this engine is about 20 per cent. of the pressure of the steam on the piston. The engine is, no doubt, too powerful for the work to be performed, the steam being reduced in its passage to the cylinders. And it will be seen that the velocity of the pistons was very great, equal to 370 feet per minute.

Andrew's House Engine, Marley Hill Colliery.

This is an engine of an entirely different construction from any of the preceding, a Ground Plan, Front Elevation, and End View being shewn in *Plate IV.*, Figs. I., II., and III., and a general description of which has been hereinbefore given. The two cylinders are 13 inches diameter each, length of stroke 24 inches; on second motion, driving wheel 2 feet 10 inches diameter, and wheel on sheave shaft 4 feet 10 inches diameter. The diameter of the 2 vertical friction sheaves is 5 feet, and of the horizontal sheaves 4 feet 4 inches. One boiler works the engine, being placed at bank, 28 feet long, and 6 feet 4 inches diameter; evaporating surface 23,426 square inches. The fire grate is 6 feet long, 4 feet 4 inches wide. The steam is taken down the pit in pipes 5 inches in diameter; the depth of the pit is 87 yards; the boiler being 39 yards from the top, and the engine 11 yards from the bottom of the pit; the distance the steam is conveyed is therefore 137 yards, 87 of which are vertical. There is a receiver at the bottom of the pit, 5½ yards from the engine, area 97·716 cubic inches.

The plane which this engine works, as shewn in *Plate III.*, Figs. VII. and VIII., is double, with an endless rope. The sheaves are 5 inches diameter, axles $\frac{7}{8}$ inch, weight $12\frac{1}{2}$ lbs, and there are 316 on the plane. There is a small carriage goes in front of the train, on which is placed a clamp to lay hold of the rope. This carriage weighs 6 cwts. 3 qrs. 7 lbs; wheels 14 inches; rope 2000 yards, $2\frac{3}{8}$ inches circumference, weight per yard, 3 lbs.

EXPERIMENT made on Fixed Engine, with Endless Rope, at Andrew's House Colliery.—March, 1855.

Number of Experiment.	No. of Tubs.		Time of Experiment.	Pressure of Steam per Square Inch.		Length of Plane.	Descent of Plane.	Inclination of Plane.	Weight of Tubs.		OBSERVAT.
	Loaded.	Empty.		Boiler.	Receiv.				Loaded.	Empty.	
			M. S.	lbs.	lbs.	Feet.	Feet.		lbs.	lbs.	
1	14	14	Comenc.	28·	28·	2788·5	22·45	1 in 124·2	20,594	8,330	From end of Plane.
			0·30	28·	27·5						
			1·	27·75	27·						
			1·30	27·75	26·75						293 double strokes in each Cylinder.
			2·	27·5	26·5						
			2·30	27·5	26·						
			3·	27·5	26·75						
			3·30	27·25	26·75						
			4·	27·25	26·75						
			4·30	27·25	26·75						
			5·	27·	26·5						
			5·30	27·	26·5						
2	14	14	Comenc.	27·5	27·	2788·5	22·45	1 in 124·2	20,594	8,330	From end of Plane.
			0·30	27·25	26·5						
			1·	27·25	26·						
			1·30	27·	26·						293 double strokes in each Cylinder.
			2·	27·	25·75						
			2·30	26·75	25·						
			3·	26·5	25·25						
			3·30	26·5	25·						
			4·	26·25	25·						
			4·30	26·	25·						
			5·	26·	25·						
			5·30	26·	25·						
3	14	14	Comenc.	26·75	27·	2788·5	22·45	1 in 124·2	20,594	8,330	From end of Plane.
			0·30	26·5	26·25						
			1·	26·5	26·						
			1·30	26·5	25·75						293 double strokes in each Cylinder.
			2·	26·25	25.75						
			2·30	26·25	25·						
			3·	26·	25·						
			3·30	26·	25·						
			4·	26·	25·						
			4·30	25·75	25·						
			5·	25·75	25·						
			5·30	25·75	25·						

Table VII, of the Result of the foregoing Experiments.

POWER.								
Number of Experiment.	Diameter of each Cylinder	Area of Two Pistons.	Pressure of Steam per Exper.	Total of Amount Power in pounds.	Length of Stroke of Pistons.	No. of Strokes per Exper.	Space passed over in feet.	Total Amount of Power in pounds, moved one foot.
	Inches.	Sq. In.	lbs.		Feet.			
1	13	265·46	26·8	7114·32	2	586	1172	8,387,983
2	..	....	25·5	6769·23	..	586	1172	7,933,537
3	..	....	25·5	6769·23	..	586	1172	7,933,537

RESISTANCE.							
Number of Experiment.	Gravity of Lead.	Friction of Carriages.	Friction of Rope, Sheaves, &c.	Gravity of Rope.	Total Amount of Resistance in pounds.	Space passed over in feet.	Total Amount of Resistance in pounds, moved one foot.
	lbs.	lbs.	lbs.	lbs.			
1	99	396	383	48	728	2788·5	2,029,928
2	99	396	383	48	728	2788·5	2,029,928
3	99	396	383	48	728	2788·5	2,029,928

The average performance of this engine is 25 per cent., but there is a considerable amount of friction by the rope being so tightened by the stretching apparatus at the two ends of the plane. It will be seen however by *Plate I*, Fig. VIII, that for a distance of nearly 200 yards there is a rise of 1 in 100 with the load, and for a distance of 154 yards a rise of 1 in 73 with the empty carriages; which makes the performance nearly 40 per cent. on the passage of the trains over those portions of the road.

No. 3.—EXPERIMENTS on an Engine dragging Coals along Levels, and also along a Crosscut to the Dip, and likewise pumping Water.

BLACK BOY COLLIERY.

The form of this engine is given in *Plate III.*, Fig I, being a Ground Plan, Fig. II, a Front Elevation, and Fig. III, an End View. The two

cylinders are 12 inches diameter each, 2 feet stroke; on second motion, driving wheel 3 feet 4 inches diameter, and wheel on rope roll axle, for both sets of rolls, 6 feet diameter. There are 4 rope rolls:—two, for the Howlish plane, 5 feet 6 inches diameter at starting, and 6 feet 6 inches when rope is on—and two, for the Woodside plane, 4 feet 6 inches diameter at starting, and 5 feet 10 inches when rope is on; axles of rope rolls, 5 inches. The engine is placed at the bottom of the pit, the boilers being at bank. 3 boilers, 31½ feet long, 5½ feet diameter; 26½ feet long, 5½ feet diameter; and 25 feet long, 5 feet diameter respectively; but two only are at work at a time. Evaporating surface 173·25 feet, 167·75 feet, and 125 feet respectively. Fire grate 5 feet 3 inches long, 4 feet wide. The boilers are distant from the engine, 10 yards from pit, 130 yards down the shaft, and 20 yards to reservoir, = 160 yards. Steam pipes 8 inches diameter; reservoir 12 feet long, 3 feet diameter, 11 yards from engine; pipes 5 inches to cylinders. The exhaust steam is conveyed up the shaft to bank, in pipes 10 inches diameter; the pit being a downcast shaft.

A plan and section of the planes which this engine works are shewn in *Plate I.*, Figs. X., XI., and XII., it is a double line of road to where the Woodside plane branches off, and then both planes are single. Both planes are worked by main and tail ropes, the ropes in both cases being three times the length of the respective planes. The Howlish main rope 1100 yards, and tail rope 2200 yards, both 2 inches circumference, 1¾ lbs per yard; Woodside main rope 1100 yards, 2⅝ inches circumference, 3 lbs per yard; tail rope 2200 yards, 2 inches circumference, 1¾ lbs per yard. The rollers for the main roads are 4 inches diameter, axles ⅝ inch, weight 16 lbs each; sheave at end of planes 3 feet 9 inches diameter, axles 3 inches, weight 6 cwt; sheaves for tail ropes 5¼ inches diameter, axles ⅝ inch, weight 18 lbs each. There are 76 rollers and 72 sheaves on the Howlish plane, and 96 rollers and 91 sheaves on the Woodside plane; with 6 drum sheaves at turn of the Woodside plane, each 3 feet diameter, axles 1¾ inch, weight 3 cwts.

***EXPERIMENT made on the Fixed Engine at Black Boy Colliery.—April,* 1855.**

No. of Experiment.	Number of Tubs.	Time of Experiment.	Pressure of Steam per Square Inch, Boilers.	Pressure of Steam per Square Inch, Reserv.	Length of Plane.	Descent of Plane.	Inclination of Plane.	Weight of Tubs.	OBSERVAT.
		M. S.	lbs.	lbs.	Feet.	Feet.		lbs.	
1	40 Empty Tubs.	commenc't.	38·	36·	2865	7·5	1 in 382	13,440	From shaft to the Howlish Bank. 270 double strokes in each Cylinder.
		0·30	37·5	35·5					
		1·	37·	34·75					
		1·30	36·5	34·5					
		2·	36·5	34·25					
		2·30	36·	34·					
		3·	36·	34·					
		3·30	36·	34·					
		4·18	36·	34·					
2	40 Loaded Tubs.	commenc't.	37·5	36·	2865	7·5	1 in 382	44,230	From shaft to Howlish Bank. 270 dble. strks. in each Cylind. Ordinary day's work from Howlish, 11 sets of 40 tubs each.
		0·30	37·5	35·75					
		1·	37·5	35·75					
		1·30	37·5	37·75					
		2·	37·	35·5					
		2·30	37·	35·25					
		3·	37·	35·					
		3·30	37·	34·75					
		4·	37·	35·25					
3	80 Loaded Tubs.	commenc't.	38·	35·5	2076	4·	1 in 519	88,460	From 5-quar. staple to shaft. 196 dble. strokes in each cylind. Ordinary day's work from 5-quarter staple, 14 sets of 40 tubs each.
		0·30	38·	35·5					
		1·	38·	35·25					
		1·30	37·75	35·5					
		2·	37·5	35·5					
		2·30	37·5	35·5					
		3·	37·5	35·75					
		3·30	37·5	36·	Engine stopped at			Siding.	
4	18 Empty Tubs.	commenc't.	38·	36·25	2850	38·	1 in 75	6,048	From shaft into Woodside Bank. 289 double strokes in each Cylinder.
		0·30	38·	36·					
		1·	37·75	35·75					
		1·30	37·75	35·75					
		2·	37·75	35·75					
		2·30	37·75	35·5					
		3·	37·75	35·5					
		3·30	37·75	35·5					
		4·	37·75	35·5					
		4·30	37·75	35·75					
		5·	38·	36·					
5	18 Loaded Tubs.	commenc't.	37·5	36·25	2850	38·	1 in 75	19,908	From Woodside Bank to shaft. 289 dble. strks. in each Cylinder. Ordinary day's work from Woodside, 24 sets of 18 tubs each.
		0·30	37·5	36·					
		1·	37·25	35·					
		1·30	37·25	35·					
		2·	37·25	35·					
		2·30	37·	35·25					
		3·	37·	34·75					
		3·36	37·	35·					
		3·45	37.	35·5					

Table VIII, of the Results of the foregoing Experiments.

POWER.								
Number of Experiment.	Diameter of each Cylinder	Area of Two Cylinders.	Pressure of Steam per Exper.	Total Amount of Power in pounds.	Length of Stroke of Pistons.	No. of Strokes per Exper.	Space passed over in feet.	Total Amount of Power in pounds, moved one foot.
	Inches.	Sqr. Ins.	lbs.		Feet.			
1	12	226·19	34·5	7803·5	2	540	1080	8,427,780
2	..	....	35·5	8029·7	..	540	1080	8,672,076
3	..	....	37·5	8482·	..	397	784	6,649,888
4	..	....	35·7	8075·	..	578	1156	9,334,700
5	..	....	35·3	7986·	..	578	1156	9,231,816

RESISTANCE.							
Number of Experiment.	Gravity of Load.	Friction of Carriages.	Friction of Rope, Sheaves, &c.	Gravity of Rope.	Total Amount of Resistance in pounds.	Space passed over in feet.	Total Amount of Resistance in pounds, moved one foot.
	lbs.	lbs.	lbs.				
1	35·	164·	251·	....	450·	2865	1,289,250
2	116·	540·	251·	....	675·	2865	1,933,875
3	171·	1080·	251·	....	1160·	2076	2,408,160
4	81·	74·	372·	....	527·	2850	2,001,950
5	265·	243·	372·	....	880·	2850	2,508,000

The average performance of this engine on both planes is only equal to 24 per cent. of the pressure of the steam on the pistons. The performance in the 3rd Experiment is, however, equal to 36·2 per cent. on the average inclination of 1 in 519 in favour of the load, whereas on a portion of the road the inclination is against the load. On the Woodside plane the average inclination is taken, whereas for 274 yards the inclination is 1 in 40, which raises the performance up to 34·4 per cent.

Besides the above performance of 34·4 per cent., the engine raises by means of a crank upon the axle of the sheave a, *Plate I,* Fig. X, a column of water 20 feet in height. The working barrel is 10 inches in diameter, the length of stroke 2 feet, and the sheaves a, being 3 feet 9

inches diameter; the piston of the pump makes 280 strokes for every train drawn in each direction. The length of the plane of this engine is now extended.

GENERAL RESULTS OF THE FOREGOING EXPERIMENTS.

The practical conclusion resulting from these experiments appear to be, that in the application of engines of the first description, page 276, viz., Engines dragging coals from the dip with a single rope, and where the inclination is such that the empty set of tubs or waggons drags the rope out from the engine; that these engines are capable of realizing an efficient performance equal to 50 per cent. of the pressure of the steam on the piston.

And, Engines working on planes requiring a tail rope, working round a sheave at the end of the plane to drag the empty set and main rope out from the engine, pages 276 and 277; the efficient performance may be safely calculated at 40 per cent. of the pressure of the steam on the piston.

These conclusions are arrived at on the supposition, that with wheels of a diameter of 12 inches, the friction of the carriages is equal to the $\frac{1}{33}$nd part of the weight; and that with wheels of $7\frac{1}{2}$ inches in diameter the friction is equal to the $\frac{1}{33}$rd part of the weight; and that where the diameter of the sheave to that of the axle is as, 4 : 1, the friction of the rope and sheaves is equal to the $\frac{1}{28}$th part of their weight. Any variation, by lessening the amount of friction of the carriages, or by an increased diameter of the sheaves; will, of course, affect the results, and must be considered in arriving at a correct conclusion.

While, however, as above explained, the engines are capable of yielding an efficient performance of 50 and 40 per cent. of power respectively; it will not be advisable in practice to erect engines, the nominal power of which is not greater than 50 per cent. above that of the efficient performance, calculated on the principles of the foregoing calculations. It will be advisable, probably, that the practical or efficient performance, should not be calculated at a higher standard than 30 per cent., or about one-third of the pressure of the steam on the piston, the velocities of the load, and of the piston being equal.

GENERAL SYSTEM OF MECHANICAL CONVEYANCE OF COALS UNDERGROUND.

Having determined the powers and capabilities of the different descriptions of motive power which may be employed in the conveyance of coals underground, we can now apply them to an imaginary coal field; for the purpose of showing, that by one or other of the applications of those mechanical powers, and with the aid of horses only as auxiliaries to those powers, the coals from any part of such coal field can be conveyed to the bottom of the pit.

Let us suppose the space within the square ABCD, *Plate I*, Fig. I, to represent a coal field of four square miles in extent, the pit P, being in the centre thereof; and suppose the coal beds to lay at an angle of 4° 50′ or 1 in 12, rising in the direction AB, and DC, the water level line being at right angles thereto, along the lines AD, and BC. The extreme distance from the pit, to the full rise or dip, and water level, being, consequently, one mile.

1st.—We have found that the margin of the action of the self-acting plane is 1 in 30. Let the lines Pa, and Pb, represent an inclination of 1 in 30. Then all the coal above those lines, or within the area Pa, Bcb P, is capable of being conveyed to the pit P, by self-acting planes, either by the plane Pc, direct to the pit, which will be an inclination of 1 in 12; or by other planes, such as Pa, or Pb, or by the short planes de and fg, to the lines Pa, or Pb; and so by the planes fP, and dP, to the pit. The coal within the area PhBCiP, can also be conveyed down to the roads Ph, and Pi, by the self-acting planes ha, kl, mn, or ib, and so to the pit by the roads Pkh, or Pmi, worked either by horses or engine power, as hereinafter explained.

2nd.—We have ascertained, likewise, that with the carriages, or tubs, as at present constructed, the inclination of a road, to be worked by horses, and to produce a maximum effect, must be laid out at an inclination of 1 in 130. Let the lines Ph, and Pi, represent such roads; then if horses are employed, the coal within the area PhaP, and PibP, will be conveyed along such roads to the pit P. It is not absolutely necessary, as will be hereafter shown, that horses should be employed on these roads, as in the cases of the Elemore, East Minor, Marley Hill, and Killingworth collieries, fixed steam engines are employed. If, however, the dis-

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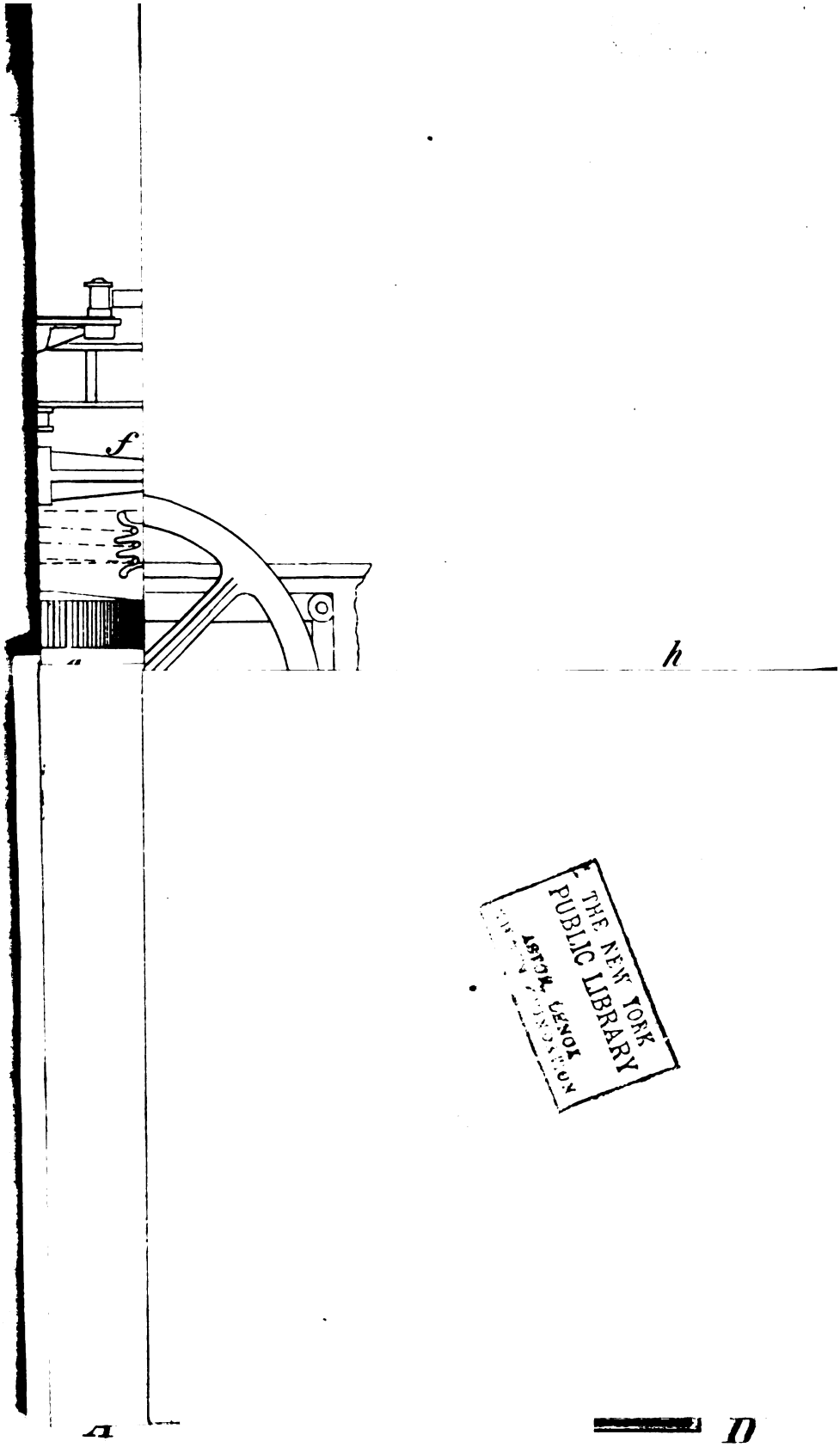

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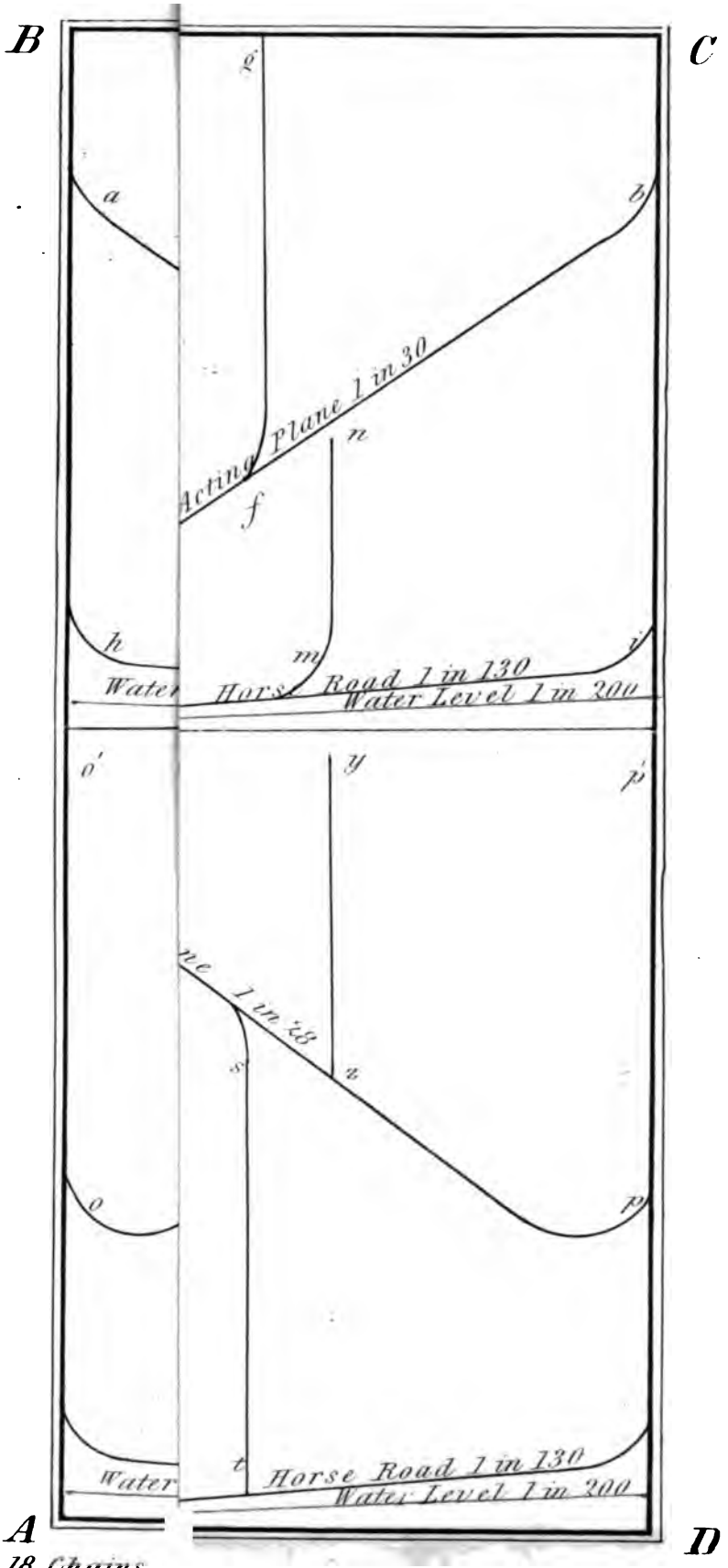

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tances are short, or the quantity of coals to be brought out is small in amount, and engine power cannot be profitably employed; then these roads, at the inclination of 1 in 130, will produce a maximum effect with horses.

The preceding observations apply to, and embrace, the conveyance of the coal above the level of the pit, the remaining portion of the supposed coal field, viz., PhADiP, is to the dip, or deep, of the pit; the conveyance of which to the pit P, will require fixed engine power.

3rd.—We have seen, that at an inclination of 1 in 28, the empty tubs, or carriages, will drag out the rope of a fixed engine, without the aid of a tail rope, similar to the engines at the Eppleton, Springwell, Killingworth, and East Minor pits. Let the lines Po, and Pp, represent the line of inclination of 1 in 28. Then engines of this description can be employed for the conveyance of coal on this portion of the coal field, either direct from the pit, the inclination being 1 in 12, as Pv,—along the lines of 1 in 28, Po, and Pp; or along a portion of such lines, and then direct to the dip, by the branching planes qr, and st. And, we have seen that those engines may either be placed at the top of the pit, the ropes leading down such pit;—or they may be placed at the bottom of the pit, and in the last case, the boilers may be either placed on the surface, the steam being conveyed down the pit in pipes, or they may be placed with the engine at the bottom of the pit.

This description of engine plane would, therefore, convey the coal to the pit P, from all the points or stations x, o, r, v, t, p, and z, or any variation of planes terminating at those stations; and the self-acting planes wx, o′o, yz, or p′p, would convey the coals down to the engine planes Po, and Pp;—while the engine planes, as in the cases of Eppleton, Springwell, &c., would, by landings between P, and V; q, and r; or s, and t; convey the coals between the line of planes Po, and Pp, and the horse road vr, and vt, to the pit P. This system of engine and self-acting planes, comprises therefore, the conveyance of all the coal situated below the level, or to the deep of the pit to the bottom of the shaft P, with the exception of the conveyance along the horse roads, which we shall now consider.

4th.—It has been ascertained, as before stated, that an inclination of 1 in 130, with the present description of carriages in use underground, will produce a maximum effect, or that the resistance of the loaded tubs down, will be equal to that of the empty tubs up, such a plane; whether, therefore, horses or engine power is intended to be used, it is alike

advisable, that this inclination should be endeavoured to be established on the levels of the mine.

I am aware, that this is a greater rate of inclination than is required for the water levels, the passages for which may be driven at about 1 in 200. But it is a subject of considerable importance, and will entirely depend upon the local, or particular circumstances of each mine, if it be advisable, in order to preserve correct water levels, that the horse roads should be driven at the same rate of inclination and thereby subjecting the motive power which convey the coal, for probably several years, to an increased rate of cost. At all events, having that rate of inclination which will produce a maximum effect, it must be left to the judgment of the engineer in charge of the mine, to determine to what extent the influence of other considerations justifies a departure therefrom.

Returning to the consideration of the motive power to be used on the horse roads. We have seen by the experiments hereinbefore given, and by the description of the engines No. 2, page 294, viz., the Elemore and East Minor engines at Hetton Colliery, and the Killingworth, Marley Hill, and Black Boy engines; that those engines are employed on what were formerly the horse roads of those collieries. These description of engines will, therefore, by providing for the conveyance of the coals from those portions of the coal field not hereinbefore provided for, complete the system of conveyance of coals by fixed engines underground; and, with the aid of self-acting planes, will show by what means the whole of the coals, in such a coal field as that represented by *Plate V*, can be conveyed to a central pit P, without the aid of horses, except as auxiliaries to those mechanical powers, at the landing of the different planes. And I may add, that this is only necessary in few cases, as in all ordinary cases the roads may be so arranged that the different planes may be worked with each other, and at the bottom of the pit, without the aid of horses.

I have, in the last description of engine power, purposely given examples of those planes where the curves are very considerable, and where the planes are by no means in a straight line, such as the Elemore and Black Boy planes; and where, likewise, the undulations are very considerable, beyond that where the tubs or carriages will run of themselves, and where they would over-run the hauling rope, were they not prevented from doing so by the tail rope.

These curves and undulations show, that the application of such planes may be varied to a considerable extent from those of straight lines, and from planes of uniform gradients; and are such as will meet almost, if

not entirely, any case between the self-acting plane of 1 in 30 descending, and engine power of 1 in 28, where the gravity of the tubs will overhaul the rope.

It cannot, however, be assumed that the case brought forward in *Plate V*, represents all the varied circumstances of coal fields in general, where the occurrence of dykes and faults, disturb the continuance or regularity of the strata, or where variations of the inclination of the beds of coal interrupt or break the continuity of planes laid out with a specific inclination, for the application of a particular description of motive power. The case is given to illustrate, the particular application of the different descriptions of motive power; and to show, in what manner the whole of the coal of such a coal field, can be conveyed to a central pit by mechanical means.

It would lengthen this paper, much beyond the limits of what is either necessary or advisable, to go into the consideration of how or in what manner such variations or interruptions as those above alluded to, should be met; this must be left to the judgment of the engineer in charge of the mine, and having before him, besides his own experience, the principles, and the practical performances of the different descriptions of motive power, which I have endeavoured to illustrate. It will be for him to consider, whether any of them, in the ordinary circumstances of the mine, or whether, with probably a moderate expenditure of capital; some one or other of those mechanical modes of conveyance may not be adapted to almost every case in practice, without having recourse to the expensive and tardy system of horse labour.

And I may, in conclusion, be allowed to point out, that if the inclination of the beds of any coal field is greater than that assumed in *Plate V;* then the margin of the application of self-acting planes to the rise of the pit; or of engine planes, where the gravity of the tubs overhauls the rope, will be more extended; and the necessity of horse power, or the application of engine power with tail ropes, will be correspondingly diminished:—And the triangles Pab, and Pap, will be extended; and the triangles Poa, and Ppb, will be diminished. On the contrary, if the coal field is more level, or less than an inclination of 1 in 12, then the contrary will be the effect, the triangles Pab, and Pop, will be diminished in extent, and the triangles Poa, and Ppb, will be extended in area; and the application of self-acting planes, and engine power with a single rope, will be diminished, and the application of engine power with tail ropes extended. And, if the beds of a coal field should be level, or not

reaching an inclination of 1 in 28, or 1 in 30; then self-acting planes, and engines where the gravity of the train is to overhaul the rope, cannot either of them be applied; and the entire conveyance will have to be accomplished by either horses, or engines with tail ropes; unless breaks, or variations in the strata occur, when by a moderate expenditure of capital, one or other of the other descriptions of motive power can be applied.

It was my intention, and I had made several experiments for that purpose, to have investigated the loss of power, by the transmission of the steam from the boilers to the cylinders; either, by its conveyance down the pit in pipes, where the boilers are on the surface and the cylinders underground; or, by its conveyance from thence, or from the bottom of the pit, to engines placed at a distance therefrom, but I found it would have extended this paper too much. I shall, therefore, at a future time, and as an appendix to this paper, trouble the Institute with some observations, and experiments on this subject; with a view of ascertaining, to what distances steam engines can be placed from the shafts, or in extension of engines conveying coals direct to the shafts, up which the coals are to be drawn; and thus to determine, how far the system of engine power can, in deep pits and expensive winnings, be economically extended, in substitution of the sinking of such pits or winnings.

NORTH OF ENGLAND INSTITUTE

OF

MINING ENGINEERS.

MONTHLY MEETING, THURSDAY, MAY 3, 1855, IN THE ROOMS OF THE INSTITUTE, WESTGATE STREET, NEWCASTLE-UPON-TYNE.

T. J. TAYLOR, ESQ., IN THE CHAIR.

The minutes of the Council having been read,

The CHAIRMAN apologised for the absence of the President, and the meeting proceeded with the election of gentlemen proposed at the previous meeting, and after the votes had been taken, the following were elected :—Mr. Robert Cadwallader, Ruabon Colliery, Wrexham; Mr. William Hynde, Ruabon Iron Works, Wrexham; Mr. Samuel Dobson, Newport, Monmouth; Mr. William Hobbs Ware, the Ashes, Stanhope.

The CHAIRMAN then said, that the first business before them was the discussion regarding the paper of Mr. P. S. Reid, on "Blowers of Explosive Gas," in order that the objection of Mr. Atkinson to a calculation in the paper be fairly considered and settled. As Mr. Reid, however, was not present, he (the Chairman) did not think they could with propriety enter upon the subject, and there appeared no alternative but to adjourn the consideration of the subject at issue until the next meeting. In the absence of Mr. Reid he thought they might devote their time in discussing the summary of Mr. Atkinson's paper "On Mining Science," and with that view he should be glad to hear any observations from any gentleman present.

Mr. M. DUNN suggested, that it would be better to postpone the subject until they had before them Mr. Wood's observations on it.

The CHAIRMAN—Then, in that case, he would have to adjourn the meeting, as there was nothing else before it for consideration.

Mr. DUNN—If so, perhaps Mr. Atkinson would oblige them with a brief summary of the subject.

Mr. ATKINSON thought it would be a difficult task to do so, as he had not seen the paper since he wrote it and sent it to the Institution. He should, therefore, prefer reading the whole of it.

The CHAIRMAN suggesting such a course,

Mr. ATKINSON then proceeded and read the paper.

At the termination of the reading of this paper, the CHAIRMAN suggested that the discussion of it be postponed until the next meeting, which was agreed to.

Mr. BERKLEY, previous to the meeting separating, called attention to the importance of the Institute being furnished with Parliamentary papers connected with the Coal Trade, and proposed the following resolution on the subject:—

"That this Institute do purchase copies of all Parliamentary papers connected with the Coal Trade, whether they refer to the mine engineering department, the export of coal, foreign or home, or statistics of the Coal Trade generally, that may from this date be published: and that it is also desirable that when any of the before-mentioned Parliamentary documents are published, notice of such publication shall be given to the members in the Monthly Circular, and that any member wishing to purchase such publications, shall, by signifying such wish to the Secretary, within one month of receiving the notice, be provided with a copy of such publication, if the same can be obtained. Each member to pay for his own copy the price charged by the publisher."

The motion having been seconded and agreed to, the meeting separated.

SUPPLEMENTARY MATTER

TO A PAPER ON

THE THEORY OF

THE VENTILATION OF MINES,

COMMUNICATED TO THE NORTHERN INSTITUTE OF MINING ENGINEERS, IN DECEMBER, 1854, BY JOHN J. ATKINSON,

PROPOSED FOR DISCUSSION

BY THE MEMBERS OF THE INSTITUTE.

CHAPTER I.

In the introductory remarks, it is stated, on general principles, that a knowledge of the correct theory of the art of Ventilating Mines may reasonably be considered to have the following beneficial effects on the practice of the art.

1st.—That of freeing practice from an amount of empiricism, which is presumed to prevail, in the absence of such knowledge.

2nd.—That of having a general tendency to lead to improvements in the practice of the art; both directly, by reasoning and induction; and by enabling us to devise and carry out experiments having the same end in view, on systematic and correct principles; and also by enabling us more correctly to generalize the results of any such experiments and to draw true inferences from them.

3rd.—That of saving useless expenditure in trying unsuccessfully to carry out new and impracticable arrangements for the Ventilation of Mines, on the one hand; and at the same time, of

enabling us to select and determine, *a priori*, what are the best arrangements for ventilating particular mines.

As the usefulness of the paper depends, to some extent, upon the correctness of the above views, and as their confirmation by the members of the Institute might have a tendency to increase the degree of attention paid to the subject, perhaps some of the members may express their opinions as to their correctness or the contrary.

Although most of the laws enumerated as affecting the Ventilation of Mines may be regarded as being well established and generally received, yet some of them do appear to be worthy of discussion by the members of the Institute on the present occasion. Amongst those may be named (6), (7), and (8), taken in connexion with Note V, in the Appendix; because the great simplicity and generality of the law which may be considered as the general resultant of these laws, is such, as in itself to form one of the principal keys to the acquirement of an easily retained knowledge of the laws of ventilation: the generality of the law, of the pressure required to overcome the resistance being proportional to the area of the rubbing surface presented to the moving air, when other conditions are constant, renders it useful for finding the pressure required to overcome the resistances occurring in passages of almost every form and area of section: and the law of the pressure per unit of surface (8), being, further, inversely proportional to the area or number of units of surface of section over which it is to be distributed, when the velocity of the air in the passage is supposed to be constant, (proportional to the square of the velocity, when it is not constant), is both simple and general in its application.

Laws (9), (10), (11), (12), (13), and (14), may, perhaps, also be considered as deserving a passing notice in the discussion, when taken in connexion with the remarks which accompany them; as it appears as if experiments are yet wanting for their complete elucidation; or perhaps some of the members may be able to throw light upon the doubtful points, without making any special experiments for the purpose of determining them.

CHAPTER II.

This chapter has reference to the discharge of fluids under pressure, through orifices or short tubes; and the pressure due to the generation of motion, considered apart from pressure due to frictional or other

resistances; and although so far useful, perhaps does not present any particulars requiring discussion here.

CHAPTER III.

In this chapter, perhaps some of the following matters may be deemed worthy of discussion.

Section (18), so far as regards the final velocity in elastic fluids passing through confined passages, being the only velocity actually absorbing pressure except in so far as motion creates friction:—in the same section the effects of the gravitation of the air, in ascending and descending parts of an air-way, on the ventilation, are noticed; and may, if deemed necessary, be discussed.

In Section (19) some doubtful points are alluded to, which perhaps some of the members may be able to explain; or, on the other hand, be willing to prove by experiments.

In Section (20) a mode of finding the resistances presented by any "wastes," returns, or other air-ways in mines, is alluded to, and which perhaps might be resorted to in some instances with benefit.

In Section (22) it may be seen that in order to prevent the formulæ becoming too intricate, the effects of the extra degree of expansion in the air, due to a higher, as compared with that due to a lower average upcast temperature, has only been allowed for in so far as it alters the ventilating pressure, and not as it tends to increase the frictional resistance due to a given weight of air passing up the upcast shaft, this will perhaps seldom affect the correctness of the conclusions obtained by the use of the formulæ, in reference to the Ventilation of Mines, to any material extent; more especially where the resistance presented to the air by the upcast shaft forms a very small part of the entire resistance, encountered by the air, from its entering, up to the time of its leaving the mine; and again, when the quantities observed as data, do not differ very widely from those to be calculated for:—yet particular cases may occur where it is necessary, from the limited distance travelled by the air in the workings of a mine, to make allowances for the differences of expansion, causing the air to encounter resistances in upcast shafts, which are not proportional to the square of the volume of cool air circulating in the unit of time; and the following note was sent too late to the printer for insertion in the Appendix to the Memoir; as having reference to such cases, besides being useful for calculating the dimensions required in flues or chimneys,

traversed by air having different temperatures, in different parts of their extent, in order that they may be capable of circulating a given quantity of air.

Note on the Mode of Calculating the Corresponding Pressure and Discharge of Air in Mines, Flues, and Chimneys where different temperatures prevail in different portions of the routes traversed by the air:—

In mines which have only a small extent of air-ways to be traversed by the air, before being expanded in volume, by the heat of a ventilating furnace; and in flues or chimneys of manufactories, or engines, it will, perhaps, sometimes be desirable to make the necessary allowances for the effects produced on the resistances, by changes in the degree of expansion; and thus also on the *volume* and *velocity* of the air discharged; in any calculations relating to the quantity of air circulating in a given time. In order to exhibit a mode of doing this let the following notation be adopted:—

Let M_1, M_2, M_3, &c., be the specific resistances of succeeding portions of the route of the air.

Let the prevailing temperature of the air in such succeeding portions of the route be T_1, T_2, T_3, &c., respectively.

Let T be the final temperature of the air on its expulsion from the exit end of the route.

Let Q be the cubic feet of air (taken at its volume as due to some temperature t, assumed as a standard) discharged per minute, by a pressure expressed in height in feet of air column of the density due to the same standard temperature t, such height of air column being represented by P.

Let A = the area in superficial feet of the exit end of the air-way.

Then, if the air be assumed to start from a state of rest, at the entrance end of the air-way, the expenditure of pressure in air-column of the density due to the temperature T_1, in that part of the route which has the specific resistance M_1 will, (see (54) &c.), be expressed by

$$\left(\frac{459 + T_1}{459 + t}Q\right)^2 M_1$$

which, by [24] is equivalent in pressure, to a column of air having the density due to the standard temperature t, expressed by,

$$Q^2 \frac{459 + T_1}{459 + t} M_1$$

By a similar mode of proceeding, we find that the pressure required, in the part where M_2 is the specific resistance, expressed in column of air of the density due to the standard temperature t, is

$$Q^2 \frac{459 + T_2}{459 + t} M_2$$

and where M_3 is the specific resistance, we have for the pressure, in air-column of standard density

$$Q^2 \frac{459 + T_3}{459 + t} M_3$$

and we could thus find the pressure due to each of the parts into which the air-way may have been conceived to be divided, whether the divisions were made to suit changes in the form of the section of the air-way, or of the prevailing temperature of the air; and, lastly, the expenditure of pressure, expressed in feet of air-column of the density due to T, on the generation of the final velocity with which the air leaves the exit end of the air-way, is, by [10]

$$\frac{\left(\frac{459 + T}{459 + t} Q\right)^2}{231{,}600\ A^2}$$

which pressure is expressed in feet of air-column, of the density due to the standard temperature t, by

$$Q^2 \frac{\frac{459 + T}{459 + t}}{231{,}600\ A^2}$$

The entire expenditure of pressure expressed in feet of air-column of the density due to the assumed standard temperature t, required to circulate the quantity of air Q, reckoned at the volume due to the same temperature, is therefore expressed by

$$P = \frac{Q^2}{459 + t} \left\{ (459 + T_1)M_1 + (459 + T_2)M_2 + (459 + T_3)M_3 \text{ \&c.,} + \frac{459 + T}{231{,}600\ A^2} \right\}$$

and hence the quantity of air put into circulation by any assumed ventilating pressure P is

$$Q = \sqrt{\frac{P\ (459 + t)}{(459 + T_1)\ M_1 + (459 + T_2)\ M_2 + (459 + T_3)\ M_3 \text{ \&c., } \ldots\ldots + \frac{459 + T}{231{,}600\ A^2}}}$$

The pressure P, must, of course, embrace the entire ventilating pressure, whether arising in the vertical or inclined parts of the shafts, air-ways, chimneys, or flues, as the case may be.

In (24), (25), (26), (27), and more particularly in (28), we have a mode of finding and comparing the specific resistances of different mines, which may be useful for calling attention to such mines as greatly require

an improved arrangement for splitting the air; whether such improvement be required in order to increase the amount of air circulating, or merely with a view of reducing the cost of producing the necessary amount of ventilation required in the mine.

The specific resistances of different mines may also be employed, in order to determine which of any number of modes of producing ventilation, whether by furnaces, fans, Hartz pumps, or otherwise, will be the most economical, in any mine of which we may have ascertained the specific resistance; provided we have the account of the ventilation produced by the same kind of machine, or power, in any other mine, of which we also know the specific resistance.

In section (29) rules are given for finding any corresponding upcast temperatures and quantities of air circulating in the unit of time, in mines where we have observed one series of corresponding upcast temperatures and quantities of air.

In section (32) the quantity l is assumed to be a constant quantity, or nearly so, in reference to the loss of temperature by cooling in any given upcast shaft; and as the loss in question has an important bearing upon the determination of the best area, for the mere purposes of ventilation, to be given to upcast shafts, perhaps some member would think it worth while making experiments to determine the law of loss by cooling in upcast shafts.

In (36) it is shown that the quantity of air put into circulation in any mine, by each lb. of coal consumed, will vary to an enormous extent with an alteration in the energy of the ventilating power employed, and in the quantity of air circulating in the unit of time, and hence the necessity of ascertaining, not only the specific resistance of a mine, but also the energy or amount of power applied in it to produce ventilation, before any correct conclusion can be drawn, as to the comparative economy in the consumption of fuel, of different modes of producing ventilation, whether such modes are tried at one and the same, or at distant times, even in the same unaltered mine.

In section (37) we see that the consumption of fuel is very nearly proportional to the cube of the quantity of air put into circulation in a given time, in the same mine, and that it is so, whether furnace or engine power is applied to create ventilation; so that we must consume 8 times the fuel, to obtain twice the quantity of air in the unit of time; and 27 times the fuel to get 3 times the air in the unit of time; so long as the state of the mine, and the arrangement for ventilation, remain unaltered, except in cases where natural ventilation prevails, so as to alter the proportion alluded to.

The loss of power in fans and also in Hartz ventilators has been found by continental Mining Engineers to be very great; but it may be questioned whether a large proportion of this loss could not be avoided, by making the valves and air passages connected with the Hartz ventilators of large dimensions; and balancing the valves in a proper manner. As Mr. Struvé's ventilating machine appears to be the same in principle as the Hartz ventilator, it appears to be desirable that experiments should be made on some of those machines, now in use in this country, in order to ascertain the loss of power in them.

One form of Mr. Struvé's machine has double the number of sets of valves, and air passages leading to them, which are used in the Hartz ventilator; and is, therefore, so much the more liable to be deranged; and this liability to derangement, both in the machine itself, and in the engine employed to work it, I hold to be one of the principal points in which the furnace is to be preferred as a ventilating power.

It is true that by doubling the number of sets of valves, as just alluded to, Mr. Struvé professes to obtain a double quantity of air, from pumps of equal dimensions with those of a Hartz ventilator; but as, in such case, the power must be increased to suit the resistance encountered by the greater quantity of air; and as the same quantity of air could be got, by the same power, by using a machine of the Hartz kind, having the linear dimensions of the pumps little more than one and a quarter times as great as those in a machine constructed on the modified principle proposed by Mr. Struvé; I consider that the old form of the Hartz ventilator is to be preferred, as being more simple, less liable to get out of order, and as economical in power.

For certainty and constancy of action, I hold that the furnace is to be preferred to any machine, or mode of producing ventilation, at present known; in all cases suited for its application; yet I strongly incline to the opinion that machines constructed on proper principles, would in almost every instance, produce ventilation at a less cost in fuel than it can be produced by furnaces. There are also some cases which admit of the application of machines, and are ill adapted for the application of furnace power, for the production of ventilation.

CHAPTER V.

It has, I believe, frequently been laid down as a principle in the ventilation of mines, that the upcast pit ought to be situated more to

the rise of the strata than the downcast pit, for the purpose of ventilation.

Where the surface of the earth is situated at the same level, at the top of each of the pits, and furnace action is employed to produce ventilation, I disagree with the above principle, as a general rule; because I think it will generally be found that the upper part of the upcast column of air will be so much more heated and expanded, than the air in the ascending workings, between the bottom of the downcast, and that of the upcast pit, that it will give a pressure, over equal vertical distances, capable of overcoming more than double the ascensional power, so to speak, of the air in such ascending workings, and whatever is to spare, beyond this, will be so much added to the general ventilating pressure, for an equal consumption of fuel.

Although as regards a level coal district, like that of Newcastle, the above may be considered as a matter scarcely deserving notice; yet in other districts, where the pits are not so deep, and where the inclination of the strata is considerable, it is not so unimportant.

In (44) and (45) we have rules for finding the quantities of air which will pursue each of a series of routes open to it, by means of the specific resistances of the routes, when a general and equal ventilating pressure operates over the whole of the routes.

We also have a mode of finding the resistance due to a passage which would transmit a quantity of air, in a given time, equal to the total quantity of air transmitted by the united action of any number of such routes under the same pressure.

At page (124) we have a tabular statement of the coefficient of Frictional Resistances, presented to the passage of air, by different substances, against which it may have to move.

Although in the case of water, the coefficient of resistance is the same, for all kinds of substances, in contact with which it has to move, yet, as regards air, it is, on the contrary, found to vary to so great an extent as to become highly interesting when considered in reference to the practice of ventilation; as it appears to hold out a prospect of enabling us to obtain a considerably increased quantity of air in a mine, by using what may be termed an anti-frictional coating, on the walls of shafts, and the main air-ways near them, with equal ventilating powers; or, on the other hand, of cheapening the cost of producing ventilation, by reducing the friction in the shafts and main air-ways; and might even save the cost of sinking additional pits, or driving additional, or larger stone drifts, to increase ventilation.

A comparison of Table 2 with Table 4, or of Table 3 with Table 5, will, at once, show how very important a matter, in the ventilation of mines, it is to have the resistances in the shafts and air-ways near them, reduced to their minimum amount. Besides, there would be a saving in the loss by cooling, if the resistances in an upcast shaft could be reduced in the manner alluded to, compared with the same amount of reduction if it had to be effected by the mere enlargement of the shaft itself.

The deep pits in the eastern part of the county of Durham, which have to penetrate the magnesian limestone, before reaching the coal measures, appear to be suited for the application of the principle suggested, as they are so costly to sink.

In the Table at page 124, it will be seen that a coating of tar or pitch on cast iron, requires only about one-fourteenth part of the pressure to overcome its frictional resistance, which was required to overcome the resistances of the shafts, and a part of the air-ways of the Crook Bank colliery, in the experiment made by Mr. G. C. Greenwell in that colliery; while the resistance offered by brick or pottery is found to be such, that it, also, requires about fourteen times the pressure to overcome it, which is required by tar on an equal surface of cast iron—other things being the same.*

It should, however, be observed that the air was heated in the experiments by which the resistance of a surface of brick or pottery was determined, while the air was cool in the experiments which determined the resistance of a surface of tar on cast iron; and it was heated over one part, and cool over another part, of the distance traversed in the Crook Bank colliery experiment; and although M. Péclet, who has made upwards of 500 experiments on the resistance of air, has concluded that the frictional resistance is not affected by the temperature of the air, still I think it might be worth while trying experiments to determine this, and also to determine the most suitable substance to be used as an anti-frictional coating for air, particularly, as the best size to be given to upcast shafts, for the mere purpose of ventilation, depends partly upon the effects of heat on the frictional resistance; and as tar or pitch is probably too inflammable a substance to be used as an anti-frictional coating in an upcast shaft.

* See subsequent remarks on certain errors, arising from Mons. Girard's miscalculations, which had not been discovered when the above was written. The discovery of the error, in the coefficient of Girard, for cast iron pipes, does not affect the principle alluded to, as other substances may present even smaller resistances.

The coefficient of friction for steam in Mr. Rudler's experiment, alluded to in Note II, in the Appendix, agrees very closely with that of air in cast iron pipes, covered with soot, if we presume that the friction increases in proportion to the barometrical pressure, and if we take the steam as having escaped under the pressure in the boiler, in Mr. Rudler's experiment. As, however, it is not stated that the pipe was of cast iron in Mr. Rudler's experiment, some doubt may perhaps exist as to whether this was so or not.

As the friction of steam in pipes has a bearing upon the question of the expediency of placing the boilers of an underground engine, in the mine, or on the surface, it is hoped that the paper now being brought before the Institute, by the President, may contain some information as to the loss of pressure arising to steam in traversing long pipes.

Note III, in the Appendix, shows that the coefficient of friction, due to gas in ordinary gas pipes, as given by Mr. Hawkesley, agrees almost exactly with the coefficient of friction due to water, as given by Eytelwein, in Note IV.

The construction of the formulæ in Notes III and IV agree very closely with those given in the Memoir.

Note V indicates that an acquaintance with the laws governing the flow of gas through pipes, was, a short time ago, at any rate, rather uncommon, even amongst gas engineers; and Mr. Anderson's letter strongly corroborates the correctness of the formulæ given in the Memoir.

The erroneous rules given by Dr. Ure, in his Dictionary of Arts, Manufactures, and Mines, when treating of the flow of gas through pipes, confirm the statement of Mr. Anderson in reference to the lack of knowledge on the subject.

Tables 2, 3, 4, and 5 exhibit, in a general manner, the benefits resulting from splitting the air in mines, in a judicious manner, when the splits are nearly equal to each other in every respect.

The shaft resistances in Tables 2 and 3 are taken at a considerable amount, and equal to many cases which may exist in practice. From Table 2, it appears that, with the same *ventilating pressure*, upwards of fifteen times the quantity of air would circulate in such a mine, when divided into fifteen equal splits, which would have circulated before splitting the air; so that there would be more air in each split, and it would only have one-fifteenth part of the workings to ventilate.

In order, however, to realise the above, it would require a consumption of fuel proportional to the quantity of air circulating in the unit of time,

or nearly so; whether the ventilation were produced by furnaces, or by engine power applied to a ventilating machine.

In the same mine, it would have required the consumption of fuel, or the engine power to have increased as the *cube* of the quantity of air circulating, to have produced the same amount of ventilation without splitting the air; thus, the consumption of fuel, and the engine power, must have been increased to 3,375 times its original amount, to give fifteen times the quantity of air in the unit of time without splitting.

It appears to be desirable that experiments should be made to ascertain something like the law by which the consumption of fuel, by any given furnace, increases, with an increase in the quantity of air passing over it in the unit of time.

If the fuel burnt by any given furnace increases in the direct proportion of the quantity of air passing over it in a given time, then the results given in Table 2 would nearly represent those which would arise from splitting the air, without making any alterations in the furnaces by which ventilation is produced.

In Table 3 are exhibited the results of dividing the same example mine, as is referred to in Table 2 into different numbers of equal splits, as described in the paper; on the supposition of the power employed to produce ventilation being constant; and hence, on that of the ventilating pressure decreasing in the same ratio that the air is increased, as the resistances become reduced by splitting the air. On this presumption the fuel consumed in furnace action, would remain constant; and it would also be realized by an engine applied to produce ventilation through a machine, or very nearly so.

From this Table it would appear that if an engine, or a furnace consuming an invariable quantity of fuel in the unit of time, circulated 16,198 cubic feet of air per minute, before splitting, it would circulate 92,616 cubic feet per minute, in the same example mine, after being divided into 9 equal splits, under the conditions named in the Memoir; each split having 10,291 cubic feet of air per minute in it, and only having one-ninth part of the workings to ventilate.

Table 4 exhibits the effects of splitting the air in a mine, having the same extent of workings as that alluded to in Tables 2 and 3, but with constant resistances, due to the shafts and the air-ways in the vicinity of the shafts, of much less amounts; under the same constant ventilating pressure as in Table 2.

A comparison of Tables 2 and 4, exhibit, in a striking manner, the great benefits which would result to ventilation, either by reducing the cost of producing a given ventilation, or by increasing the ventilation in amount, to be expected to result from any means of reducing the common resistances in the shafts and adjoining air-ways. A few of the results are given in the following tabular statement, in which the ventilating pressure is presumed to be constant.

With the larger amount of resistances in the Shafts, and in the air-ways over which the whole of the air passes, in the vicinity of the Shafts, as in Table 2.			With the reduced resistances in the Shafts, and in the air-ways through which the whole of the air passes, in the vicinity of the Shafts, as in Table 4.		
Number of Splits.	Total quantity of Air circulating in cubic feet per minute.	Quantity of Air in each Split in cubic feet per minute.	Number of Splits.	Total Quantity of Air circulating in cubic feet per minute.	Quantity of Air in each Split in cubic feet per minute.
1	7,288	7,288	1	7,302	[illegible]
2	20,328	10,164	2	29,623	[illegible]
4	52,129	13,032	4	57,807	14,452
6	78,566	13,095	6	103,550	17,258
8	94,652	11,831	8	152,770	19,096
10	103,280	10,328	10	200,000	20,000
20	113,704	5,685	20	341,126	17,056
30	114,939	3,831	30	379,472	12,649
40	115,245	2,881	40	390,941	9,774
50	115,355	2,307	50	395,285	7,906

In order to have realised the above results, under the conditions named in the Memoir, would have required the engine power to have been increased in the same proportion that the air increased, as also the consumption of fuel, whether used in an engine, or in ventilating furnaces.

The results arising in the same mines, as are alluded to above, on the presumption of the consumption of fuel being constant, are exhibited in Tables 3 and 5 in the Memoir, and a few of the results are given below.

With the larger amount of resistance in the shafts and in the air-ways through which the whole of the air passes.			With the reduced resistance in the shafts and in the air-ways through which the whole of the air passes.		
Number of Splits.	Total quantity of air circulating in cubic feet per minute.	Quantity of air in each split in cubic feet per minute.	Number of Splits.	Total quantity of air circulating in cubic feet per minute.	Quantity of air in each split in cubic feet per minute.
1	16,198	16,198	1	16,127	16,217
2	32,094	16,047	2	32,404	16,202
4	60,129	15,032	4	64,420	16,105
6	79,042	13,174	6	95,088	15,848
8	89,492	11,187	8	123,153	15,394
10	94,850	9,485	10	147,360	14,736
20	101,132	5,057	20	210,365	10,518
30	101,861	3,395	30	225,850	7,528
40	102,042	2,551	40	230,377	5,759
50	102,106	2,042	50	232,080	4,641

Now, the differences, in the quantities of air circulating in the two cases, arises entirely from the resistances in the shafts and in the air-ways near them, which are traversed by the whole of the air, being, in one case, taken at little more than 1-18th part of its amount in the other case; and when it is considered, that the specific resistances, allowed to be due to the shafts and air-ways traversed by the whole of the air, is, in the one case, taken at about 1-257th part of the specific resistances of the divisible workings of the mine, and in the other case is supposed to be reduced to about 1-18th part of its previous amount, it certainly appears to hold out a fair prospect of greatly reducing the cost of producing ventilation, or of greatly increasing its amount, if any suitable anti-frictional substance could be applied to reduce the resistances in the shafts, and in the main air-ways near them—the differences in the Tables are little more than would have arisen from coating the shaft walls, and main air-ways near them with tar or pitch, had it been a suitable substance, as it reduces the friction to about 1-14th part of the amount given by Mr. Greenwell, as due to the shafts and air-ways in Crook Bank

Colliery, as compared with a reduction of no more than to 1-18th in the Tables. If this view as yet, partakes of the theoretical, it does so in such manner as to warrant the prosecution of experiments to prove whether it can be made available in practice or not.

In Tables (7), (8), and (9), is exhibited a general view of the comparative results, in ventilation, to be anticipated from having the splits of equal and of unequal amounts.

Table 7 presumes the power and consumption of fuel by furnaces to be directly proportional to the quantity of air circulating in a given time, and shows a loss of 30 to 46 per cent. in the quantities of air circulating, when the splits form a series in arithmetical progression, as compared with the splits being all equal, as stated in the Memoir.

Table 8 presumes the power and the consumption of fuel to remain invariable, and shows a loss of from 20 to 34 per cent. in the quantity of air circulating, arising from the same inequality of the splits.

Table 9 exhibits the great reduction which takes place in the pressure, power, and consumption of fuel, by judiciously splitting the air when a constant quantity is circulating, both on the supposition of the splits being equal, and also on that of their being unequal, and forming an arithmetical series, having the least split for a common difference, under the conditions stated in the Memoir. This Table shows that even when a mine may be considered to be sufficiently ventilated, it may occur that by improving the mode of splitting the air, the consumption of fuel, and the cost of producing an equal ventilation, may be reduced to a small per centage of the previous cost of producing the same amount of ventilation.

CHAPTER VI.

Presents for discussion the question as to the practicability of applying the specific resistances of air-ways, to determine, in practice the best mode of ventilating a mine in reference to splitting the air.

This chapter also opens the question as to the best mode of ascertaining the specific resistances of air-ways. Whether by taking the dimensions of the air-ways, or by observing the differences of pressure, as is proposed in the Memoir; or by any other mode to be suggested.

Can any member suggest the construction of an instrument to be used as a pressure gauge or as a barometrical instrument for finding minute differences of pressure, to a great degree of nicety, and moderately free

from the effects of heat, in altering its indications; or, on the other hand, admitting of easy and accurate corrections being applied for such effects?

Would the Institute deem it worth while to get an instrument of the kind described in the Memoir, constructed and tried?

It may perhaps be considered worth the time to discuss the conclusions arrived at, as to real meaning of the water gauge indications, both in reference to the air-ways lying between the points of observation, and also in reference to the shafts and the air-ways extending from them to the respective points of observation.

CHAPTER VII.

Presents for discussion the formulæ for finding the friction of revolving anemometers, and the mode employed on the Continent for finding the constants a and b.

CHAPTER VIII.

Contains the illustration of the application of the specific resistances of air-ways to determine, *a priori*, the effects of any proposed "change of air" in a mine.

REMARKS UPON THE PROPORTIONS OF POWER, REQUIRED TO PRODUCE DIFFERENT AMOUNTS OF VENTILATION IN THE SAME MINE.

It may, perhaps, appear from the following statement, that the consumption of fuel in ventilating mines, whether by machinery driven by engine power, or by furnace action; is, under the ordinary circumstances of mines, nearly proportional to the cube of the quantity of air circulating in the unit of time, in the same mine.

In the case of machinery driven by engine power, the ventilating pressure to be overcome is nearly proportional to the square of the quantity of air circulating, in the unit of time, in the same mine; while the velocity with which such pressure has to be overcome, is nearly proportional to the simple quantity of air circulating in the unit of time; the power of the engine, however, in this, as in other cases, is proportional to the product of the pressure or force to be overcome, and the velocity

with which it is required to be overcome; and since the former is sensibly proportional to the square of the quantity, and the latter to the quantity simply, the power and fuel being proportional to their product, must be nearly proportional to the square of the quantity, multiplied by the quantity simply, which is, in fact, the cube of the quantity of air circulating in the unit of time, in the same mine.

As an example, suppose an engine to drive a Hartz ventilator, exhausting air from a mine, as by pumping. If we would double the quantity of air without altering the engine, or machinery, the pumps would require four times the force to move them, seeing that the ventilating pressure increases as the square of the quantity of air; and hence four times the pressure must be exerted on the piston, to overcome the resistance of the air, and this additional pressure, even if exerted on the piston travelling at the same speed, would make the power four times as great; but, in fact, the piston must travel at twice its former speed, to exhaust the double quantity of air, in the same time; and the piston, working under four times the pressure, and at twice its former velocity, evidently represents eight times the original power, as being required to double the quantity of air; which increase of power is sensibly proportional to the fuel consumed, and is evidently proportional to the cube of the quantity of air. To have increased the quantity to three times its original amount, the ventilating pressure to be overcome, and hence, the pressure on the piston must have been increased to $3 \times 3 = 9$ times its original amount, and in order to exhaust the treble quantity of air, in a given time, it must have moved with three times its original speed; and this nine-fold pressure on the piston, and its three-fold speed, represents a power twenty-seven times greater than the original power, as being required to circulate only three times the quantity of air in a given time, in the same mine; so that the power, and therefore the fuel, are proportional to the cube of the quantity of air to be circulated in the unit of time, in the same unaltered mine; except in so far as the same may be effected by other or natural sources of ventilation, where machinery is employed.

The greater or less degree of expansion, created in the air, owing to the changes in the amount of ventilating pressure employed, will certainly affect the volume, and therefore the velocity, of the air, and thus, the power; but to an extent seldom worthy of notice, when it is considered that a ventilating pressure of 2 inches of water gauge, will, in general, alter the volume of air less than 1-200th part of its entire volume, if it were either entirely removed, or doubled in amount.

Taking the resistance encountered by a boat on a canal as proportional to the square of the velocity of the boat—and if we suppose an engine to drag such a boat, by a towing line folding upon a drum; then, in order to double the velocity of the boat, the strain on the towing line will be four times as great as its original amount; requiring four times the pressure to be exerted on the piston; but this fourfold pressure must be exerted on the piston travelling at twice its original speed, in order that the speed of the boat may be doubled, thus representing eight times the original power, which is proportional to the cube of the double velocity of the boat, which is the proportion in which the power and fuel vary, with a variation in the speed of the boat; and this is a case, parallel with that of an engine producing ventilation through machinery.

In the case of ventilation being produced by furnace action; while the increase of temperature to be imparted to the air, within moderate limits, is sensibly proportional to the ventilating pressure to be produced, such pressure, itself, is nearly proportional to the square of the quantity of air; and hence the increase of temperature, and the fuel expended on producing such increase, *in an equal quantity of air*, will also be proportional to the square of the actual quantity of air: but the fuel will evidently be further proportional to the actual quantity of air in circulation, and requiring to be heated; so that, on the whole, I hold, that even in furnaces, the fuel is proportional to the cube of the quantity of air to be circulated in the unit of time, except in so far as the proportion may be modified by

1°. A change in the proportion of fuel due to cooling in the upcast shaft, with changes in the temperature, and quantity of air circulating.

2°. Changes in the proportion of fuel saved by heat imparted, or lost by heat abstracted, by the walls of the mine, from the air circulating.

3°. By changes in the specific heat of the air, arising from changes of temperature, and in the weight of air expelled by heat, from the upcast shaft, at different temperatures.

4°. By the extra expansion of the air in upcast shafts at higher as compared with lower temperatures, giving rise to increased resistances, beyond what would be due to air at the same temperature.

So far as these sources operate, they will affect the ratio of the quantity of fuel, to that of the air circulating, in a given time, in the same mine; as their effects will be greater, in proportion, as the quantity of air

is lessened; so that the cube of the quantity of air will not be, strictly, although perhaps in mines where a tolerably energetic ventilation is kept up, it will be very nearly proportional to the quantity of air circulating in a given time.

REMARKS ON CERTAIN ERRORS IN THE PAPER ON "THE THEORY OF THE VENTILATION OF MINES," ARISING FROM MONS. GIRARD'S MISCALCULATIONS.

Previous to communicating the Paper on the Theory of the Ventilation of Mines, to the Institute, I had not seen Mons. Girard's detailed account of his experiments on the Transmission of Air and Curburetted Hydrogen Gas, through cast iron pipes, and wrought iron tubes; and, consequently, had to take a brief account of the deductions drawn from them, which I had in Mons. Péclet's "Traité de Chaleur:" since then, however, I have been favoured with the perusal of Mons. Girard's detailed account of his experiments, and this has led me to detect two errors, which I take this opportunity of correcting.

Mons. Girard appears to have fallen into an error, in calculating from his experiments, the constant co-efficient of resistance, due to the transmission of air or gas, through cast iron pipes, and Mons. Péclet, and myself after him, have given the same erroneous constant.

To correct this error, it is necessary to make the following corrections in my Paper on the Theory of the Ventilation of Mines.

1°—Instead of $\frac{1{\cdot}905}{100.000.000}$ being the value of the constant k, due to cast iron gas pipes, as stated in Table 1, at page 124, the value of the constant, according to the experiments, should be $\frac{4{\cdot}3436}{100.000.000}$

2°—Instead of the 2nd line of the tabular statement at page 209, of the Institute Journal, being

"Old tarred cast iron | cool | ·000,000,019,050 | 56·664 | 7·5275;"

according to the experiments it really ought to be

"Old tarred cast iron | cool | ·000,000,048,436 | 22·286 | 4·7208."

3°—Instead of the formula [n], in the tabular list of formulæ, at page 210, the true formula to agree with the experiments, is

$$V = \sqrt{231{,}600\,h} \times 4{\cdot}7208 \sqrt{\frac{D}{L + 22{\cdot}286\,D}} \quad \ldots\ldots [n]$$

The second error to which I have to solicit attention is contained in a statement in Section 10, at page 77, to the effect that the absolute amount

of pressure per unit of surface required to overcome the frictional resistance of tubes or air-ways, to the passage of air or gaseous bodies, was found by M. Girard, in his experiments with the gas-lighting apparatus of St. Louis Hospital, to be the same for the passage of the gas used for lighting, as for the transmission of air, rendering it highly probable that it is the same for the passage of all kinds of gases whatever, through the same pipe or passage.

The above statement would appear to have been made in consequence of M. Girard's first general conclusion, professing to be drawn from his experiments, which is to the following effect:—

"1°—That carburetted hydrogen gas and atmospheric air, under the same state of compression, move after the same laws, and experience exactly the same resistances in the same tubes, and this independent of their specific densities."

In point of fact, however, the experiments plainly indicate that for the passage of atmospheric air and carburetted hydrogen gas, through the same pipes, and under the same pressure the volumes discharged in a given time, are inversely proportional to the square roots of their respective densities: that this is the case, will appear by examining the following statement of experiments made by Mons. Girard; compared with calculations based upon the above law.

Number of Experiment.	Length of Pipes in Feet; the pressure per unit of surface being constant for all the experiments.	Numbers proportional to the observed discharges in the unit of time.		Discharges of Atmospheric Air, calculated from those observed of Carburetted Hydrogen Gas, taking the discharges to be inversely proportional to the square roots of the densities; and the specific gravity of Carburetted Hydrogen as ·555, to that of Air as 1.
	English Feet.	Carb. Hydrogen.	Atmospheric Air.	
1 & 4	422·58	12,180	9,023	9,074
2 & 5	1233·00	7,103	5,414	5,298
3 & 6	2043·30	5,414	3,947	4,033
Sums ..	.....	.....	18,384	18,405

This conclusion is fully borne out by the other experiments of Mons. Girard which bear upon this part of the subject.

The experiments, therefore, when considered in connection with the ascertained fact, that, when other things are the same, the volumes dis-

charged in a given time are proportional to the square roots of the pressure per unit of surface, lead to the conclusion, that if the pressure per unit of surface be estimated in height of head of air or gas, of the same density as the flowing air or gas, then will the volumes discharged in the unit of time be directly proportional to the square root of the height of such head or column, when the length of pipes, or air-ways, and other things, remain constant and unaltered; and as the formulæ given in the Paper on The Theory of Ventilation agree with this, no further alteration is required, beyond the erroneous statement alluded to in Section 10, page 77, where the statement ought to be,

"(10)—The height of head of air or gas column, of the same density as the flowing air or gas, required to overcome the frictional resistances, &c.,"

In lieu of

"(10)—The absolute amount of pressure required to overcome the frictional resistances, &c.,"

NORTH OF ENGLAND INSTITUTE

OF

MINING ENGINEERS.

MONTHLY MEETING, THURSDAY, JULY 5, 1855, IN THE ROOMS OF THE INSTITUTE, WESTGATE STREET, NEWCASTLE-UPON-TYNE.

NICHOLAS WOOD, ESQ., PRESIDENT OF THE INSTITUTE, IN THE CHAIR.

Mr. DOUBLEDAY, the Secretary, having read the minutes of the Council proceedings, then read the minutes of the last monthly meeting; after which, referring to the resolution passed respecting his instructions to procure all parliamentary papers on the subject of Mines and Mining, &c., stated that he had given a general order to Mr. Charnley, bookseller, to obtain all publications connected with the Coal Trade.

The PRESIDENT then said, they would perceive that the minutes of the Council contained nothing requiring notice from him, excepting the subject of the proposed Mining College of Engineers. They perhaps would recollect that, at a previous meeting, they were informed that a general meeting would take place in April, in London, of the representatives of the several districts of the Coal Trade in the kingdom. That meeting, he begged to inform them, had been held a fortnight ago, at which Mr. T. J. Taylor and himself were present. The subject of the establishment of the Mining College having been brought before the meeting, every gentlemen present was convinced of the great necessity which existed for the establishing of such a Mining College for the education of mining engineers and others entrusted with the management of Coal Mines. There certainly existed some difference of opinion as to

where the College should be established, some contending for the Midland Counties, and others in South Wales, where mining operations were extensive, and where it was suggested the College would be valuable as a means of instruction to persons engaged in both the Coal and Ironstone Mines; after some discussion, however, the situation of Newcastle-upon-Tyne appeared so obviously superior to any other, that it was ultimately agreed that Newcastle-on-Tyne was the most suitable place for such College, as it was admitted that there were facilities and advantages all around that district which no other part of the kingdom possessed: as, in the Newcastle district, independently of the mines being more numerous, their greater depth and, consequently, greater difficulties of management, presented opportunities for instruction to the pupils of the College which no other district in the kingdom possessed. This point having been settled, another subject of discussion arose relative to the propriety of establishing Local Schools in connection with the College; after much discussion it was finally determined that this question would be more properly left for future consideration after it was seen how the College progressed in Newcastle. In the course of the proceedings it appeared evident to every one that unless the intended College was of a first-rate character, both in respect to its management, and also with regard to the Professors, it would not succeed. It was also further represented that as the object was most important, and would comprehend the education of a most numerous class of Mining Managers, it was necessary to have the College established on a broad, comprehensive, and sound practical basis. And though there was no doubt that in the progress of time Local Schools would unquestionably be introduced, still they should be subservient to the College, and be in the nature of preparatory schools and feeders to it. Having stated thus much of the proceedings of the meeting in London, it only remained for him to inform them that a resolution was passed at that meeting approving of the Mining College, and of its great utility and importance relative to the future management of the coal mines in this country, and appointing a committee to further its establishment. So far as the tone and feeling of the meeting in London went, he might say that, as a first meeting on the subject, it was highly encouraging; and that it was represented by deputations from almost every mining district in England, Wales, and Scotland, every one of whom expressed their desire to render every support to the project. Before separating, the meeting was informed that so soon as the mode of carrying out the project was

agreed upon, a communication to that effect would be transmitted to all the districts. The proper course for the Council of the Institute to pursue, would probably be, in conjunction with the committee appointed in London, and with other persons and bodies in the district, desirous of promoting the establishment of the College; to draw up some plan for carrying into effect the entire scheme, and to lay the result before a special meeting of the Institute. In the meantime, he should be glad to hear the observations of any member touching the best mode of establishing the College in question.

Mr. DUNN enquired if an Act of Parliament could be obtained to enforce the payment of so much per ton on coals for the support of the College?

The PRESIDENT replied that such a mode had been hinted at, but it would require serious discussion before such a scheme could be proposed.

Mr. DUNN said, only to raise a certain amount. A small tax would be sufficient, because he thought it would not do to leave it to voluntary contributions.

The PRESIDENT: What they required was, first of all, a sufficient sum to erect the building. They had laid before them a beautiful drawing of a building for the purpose, and the first step was to raise sufficient funds to erect the building; and then, he presumed, the requisite funds for the payment of the salaries of the different Professors of the College, and other current expences, would be provided by annual subscriptions and by the charges made to the pupils.

Mr. DUNN: Yes, but if the principle of so much per ton were admitted, they would at once succeed.

The PRESIDENT—The principle, however, had not been generally assented to, as there were other interests to be consulted, viz., the manufacturing as well as the coal trade. He also thought that the Government ought to promote the object by giving a grant of money towards the establishment, and he hoped towards the support of such a College.

The MAYOR of Newcastle begged to observe that at the last meeting of the Town Council, a report was presented from the Committee of Schools and Charities, from which it appeared that a sum of £750 per Annum was at the disposal of the Council for the purposes of education, but that sum would ultimately reach £5000. Now, he could not say whether or not any part of that money could be applied to the purposes of the Mining College; but he must state that the report of the Committee recommended the division of the £750 in a certain way without any

notice of the College at all. A few members of the Council, including himself, said, that although the money in question ought to be strictly applied to the purposes directed by the Charity, yet they thought the Council might take a more extensive view of the matter, as in point of fact there were many institutions established for the purposes of education, which certain classes of society required, but which being too expensive, were not within their grasp. Such classes, he thought, were entitled to assistance out of the fund in question. Ultimately the report was referred back to the Committee for further deliberation, and on being presented the second time, he pledged himself to propose a resolution in favour of the proposed College of Mining Engineers. He was aware that the proposed College was intended principally for the Coal Trade, and while he was willing for it to be so, yet he trusted that in addition to the cultivation of those sciences so essential to Mining Engineers, others would be taught, including geology, chemistry, mathematics, meteorology, and other branches of philosophy, with the object of advancing the education of gentlemen whose lives were devoted to the manufacturing interests of the country. They must remember that there were many important branches of industry in regard to which coal itself was but the raw material, and he therefore trusted that the College would be established on such a broad basis as would include the great and important interests he had alluded to. With respect to the propriety of incorporating the Mining College with any other, for the purpose of embracing the entire kingdom, that, he thought, was a matter for future consideration, yet, as an inhabitant of that town, and one who had great confidence in the liberality of his fellow citizens, he might venture to say that if it was determined to to fix upon Newcastle as the site of the College, they might, if they could not obtain extraneous and proper help, find the means within themselves. This he considered quite possible when they looked at the great number of coal and lead mines in the district, together with the iron and chemical works: for it was almost impossible to produce another district in the kingdom where all those branches of trade were so much concentrated, and where a College, such as was projected, might be so easily supported. Besides, he trusted that the Corporation of that town, which was bound to watch over and foster such great interests, would come forward with that aid which the importance of the subject deserved.

The President said that he agreed with everything that had fallen from the Mayor relative to the importance of the subject to the district

generally; and he felt confident that there were ample resources within it to establish and support the proposed College. He begged, however, in reply to the Mayor, to say that it had always been the intention of the Council of the Institute to recommend, that the system of education should be suitable for all the different branches of manufacturing interests, that it should not be exclusively devoted to the mining interest, but that it should include the education of pupils connected with all the important trades alluded to. These principles he stated were already set forth in the printed prospectus of the intended College, and while he felt confident as to resources being obtained for its support in the district, yet they still looked towards extending education in other parts of the kingdom. As to the nature of the education to be given, this, as well as other details, will hereafter be brought under the consideration of those gentlemen entrusted with its establishment; but in the meantime he trusted that the Mayor, as well as other influential gentlemen of Newcastle, including all connected with the manufacturing and chemical interests would render their support in conjunction with those belonging to mining operations of the district, to ensure the establishment of such a College as would do honour to the district and confer benefit on future generations. When all these important and varied interests were brought together, that would be the most suitable time to go into the details of the course of education. In conclusion, he submitted for their consideration, that the Council should be instructed to draw up a statement to lay before the general meeting in August, with a view to bring the subject specially before the Institute, in order that some plan might be devised as to the best course to pursue to ensure success.

Mr. Dunn still was of opinion that they ought to adopt a sort of tonnage both upon coal and iron, according to their relative value. If some general principle of that sort was adopted, they could not fail to succeed.

The President doubted that it was practicable to do this at present. What they required at first was to raise a sufficient sum for the building, and next endeavour to obtain from the interests alluded to an adequate annual subscription for its support. He was of opinion, however, that if the College was once fairly established, it would, to a very great extent, be self-supporting.

The Mayor had no doubt but that it would be self-supporting. For instance the College in Edinburgh, with its 500 pupils, was self-supporting.

The President—A subscription of between £30,000 and £40,000 towards the erection of the building would at once set them a-going;

and then afterwards they might get annual contributions from gentlemen connected with the coal and other trades to support the College for a few years, until they ascertained whether it was self-supporting or not.

Mr. Boyd thought an application to Government for a sum of money towards the building would not be out of place, especially when they knew that the Edinburgh College was much beholden to the support of Government. A sum of money, it was well known, was voted by Parliament in support of that College.

The Mayor—Before applying to Parliament, they ought at least to raise among themselves between £10,000 or £20,000, as that would be a strong argument in their favour.

The President.—The Institution in Jermyn Street, London, which has been established for mining education has received support from government, not only towards its erection, but towards the salaries of the professors attached to it. If, therefore, the government subscribed to that institution, surely it could not refuse its support to so national a project as the College in question. He thought it a disgrace to the country that there was no such institution in it, especially when they considered the immense importance of the mining interests in this kingdom.

The Mayor believed that it was proposed to receive young men into the College of a certain class, but he trusted they would not preclude any whose businesses were dissimilar to mining, &c.: for instance, he should send his sons to the College to finish their education after leaving school.

The President said there could be no objection to such an arrangement. The Local Schools already alluded to, if established, might adopt such a course of education as would prepare the pupils for the College, and they would thus act as feeders.

Mr. Boyd observed, that in the Durham University there was a second-rate course of education which was not charged high, while the pupils were all eligible to the regular course of lectures.

The President, in conclusion, begged to submit the following resolution for the adoption of the meeting:—

"That the Council be instructed to cooperate with the Committee appointed in London, and with other persons and bodies in the district desirous of promoting the establishment of the proposed College, and to take such other steps as may appear to them best calculated to further its establishment."

Mr. Dunn having seconded the motion, it was put and carried unanimously.

The meeting then broke up.

NOTES
ON
MR. J. J. ATKINSON'S PAPER,
ENTITLED
"THEORY
OF THE
"VENTILATION OF MINES."

BY T. J. TAYLOR.

The subject matter of the foregoing paper is of so extended a character, that, if dealt with in detail, a comment upon it would branch out into numerous and laborious objects of investigation. The Notes I have made are, therefore, either explanatory, or intended to illustrate the practical bearings of various portions of the Memoir. I have also stated where I differ from the Author in some cases; but after a careful perusal of his paper, I cannot help expressing my opinion, notwithstanding those differences, that it is a completer *Précis* of what is known on the intricate topics of which it treats, than any other I have yet seen; and that, without great pretensions to originality, it will, at all events, form an excellent basis for those experimental researches of which the subject so largely admits.

CHAPTER I.—*No.* 2.

Some experiments, to show the effects of local changes of temperature, were tried, under my direction, in Backworth pit, with the following results:

Temperature at the upper station, 41 fathoms from surface, .. 55·8° *F.*
Ditto at the lower station, 91 fathoms below the upper, ... 65·0° *F.*

Adopting the usual law of the increasing density of air in descending, we find that the density at the upper to that at the lower station is as 100,000 to 102,118; and, consequently, the relative volumes for the same weight are *cæt. par.* as 100,000 to $\frac{100,000}{102,118} = 97930$.

The expansion due to the difference of temperature is as (459 + 55·8 =) 514·8 : (459 + 65 =) 524 :: 97930 : 99680 volumes; so that the air at the extreme deep is still heavier than at the extreme rise, notwithstanding the difference of temperature.

But another consideration remains, that of the hygrometric condition of the air at each station; in this experiment both very nearly approached saturation; and the enlargement of volume at 65° was, therefore, greater than at 55·8.

The elastic force of watery vapour at 55·8° is ·458
at 65° is ·616
(Per Dalton's Table).

Now, supposing the barometer at the upper station to be 30 inches, it would be at the lower station (30 × 1·02118 =) 30·64 nearly.

Therefore, the enlargement of volume at the upper station would be $100,000 \times \frac{30 + \cdot 458}{30} = \Big)$ 101527; and at the lower station $99680 \times \left(\frac{30\cdot 64 + \cdot 616}{30\cdot 64} = \right)$ 101684.

The final result is, that, notwithstanding the difference of 91 fathoms of level, yet, when all circumstances are taken into account, the density is, in this experiment, *less at the lower station than at the upper one.* The difference is indeed trifling, but sufficient to establish the fact.

We are not to conclude that there was a more than normal temperature at the lower station; both observations were made at levels much below the plane of invariable heat, and the difference between the two stations is nearly $9\frac{1}{2}$° for 91 fathoms, being $57\frac{1}{3}$ feet to a degree; which is *less* than the usual rate of increase.

The necessity is thus perceived of entering upon a wide field of observation and experiment in the collection of the data required to form an accurate and comprehensive Theory of Mine Ventilation. And this line of proceeding is the more imperative, because the ventilating forces employed are in themselves very trifling, seldom exceeding three or four inches of water column, and are, therefore, so much the more easily influenced by the variable circumstances of different mines, or even

of the same mine. In point of fact, the problem of the motion of air-currents presents itself to mining engineers in a more complex form than to others. We shall see more of this in the sequel.

CHAPTER I.—*Nos.* 3 *and* 4.

The rule that the velocity is equal to that of a body falling through the height of the fluid, is applicable to the velocity in the vena contracta. In the orifice the velocity is much less.

In an experiment from Rouse's Table we have the velocity of a wind put at 47·66 per second; and the pressure on a square foot equal to 5·137 lbs., but the height of column due to this velocity is ($8\sqrt{47{\cdot}66} =$) 35·4 feet, the pressure of which is only 2·7 lbs; so that nearly double the height due to the velocity is required to give the pressure. In an experiment of Girard's, the velocity of air issuing from a gasometer of sheet iron 1-13th of an inch thick, under 1·33 inch of water = 90 feet of air (1·33 × 812) 55·2 feet per second. Now, the height due to this velocity is 47·7 feet, or about the half the entire column.

CHAPTER I.—*Nos.* 5, 6, 7, *and* 8.

Another condition should in strictness be added, that of the density of the propelled fluid.

The pressure (or resistance) is directly :—

1.—As the surface, that is as the perimeter × length.

2.—As the square of the velocity.

3.—As the density, which is not, however, included by the Author.

The resistance is also inversely as the area; that is, as the number of particles amongst which the aggregate resistance is distributed.

And thus the resistance arising from the motion of air or gas in any channel is determinable by the expression,

$$\frac{\textit{Length} \times \textit{perimeter} \times \textit{velocity squared} \times \textit{density}}{\text{area.}}$$

CHAPTER I.—*No.* 10.

There is some obscurity in this which can, perhaps, be explained away. The absolute amount of pressure is not, in fact, equal for all gases, but is, *cæt. paribus*, greater for the gas of greater density.

The experiments of Girard, here alluded to, give the same constant of pressure, but in this case the motive agent is represented in gas of the same density with that which is propelled; so that the gas of least density requires also the least pressure.

For example, the expression $74\sqrt{\frac{H\,A}{L\,P}}$ gives the velocity in cast iron pipes from Girard's experiments, where H is the pressure-column, A the area, L the length, and P the perimeter; but in this case H is always in the denomination of the gas itself; if we retain H in *air* column then the expression becomes $74\sqrt{\frac{H\,A}{L\,P\,\delta}}$ where δ is the density of the gas, that of air being 1.

CHAPTER I.—*No.* 11.

The resistance diminishes as the density diminishes, and *vice versa*. When the barometer falls, the ventilating column is lessened in weight, but the resistance in the mine is also lessened.

The *volume* of air in circulation is therefore, (considered *per se*), the same; but being in some degree lighter, its efficiency as a ventilating agent is not so great as before, while the issue of gas from the mine is greater, and replaces a part of the air-current. In the course of my own experiments, I have found the volume of air greatly reduced by very high winds, not by variations of barometric pressure.

CHAPTER I.—*No.* 13.

Effect of Bends.—Bends or angles at a distance from the point of greatest pressure have a less effect than those nearer to it; and if the bends are so made as to cause an elevation in the general level of the main, their effect may be, as I shall afterwards explain, not merely *nil*, but actually favourable to an increased current. Daubuisson's and Péclet's *apparent* results may be probaby accounted for on these grounds. Clegg (gas-lighting) tried some experiments of this kind with the following results:—

	Difference.
A 2-inch pipe, perfectly horizontal, and 30 feet long, delivered 2898 cubic feet of gas	—
——— with a semicircular bend, at 15 feet, it delivered 2754 cubic feet of gas	$\frac{1}{20}$

Difference.

A 2-inch pipe, with a quadrantal bend, it delivered 2834 cubic feet of gas ..... $\frac{1}{45}$

——————— with a rectangular bend, it delivered 2824 cubic feet of gas ..... $\frac{1}{39}$

He observes that "two semicircular bends make twice the difference; three bends make thrice the difference; that a semicircular and a rectangular bend form an obstruction equal to the sum of the two, or $\frac{1}{20} + \frac{1}{39}$, and this seems to be the same under all variations of circumstances."

But it is clear that in a larger channel the effect of bends is much diminished: for example, supposing the velocities and other circumstances to be the same, with a variation only in the diameter of the pipe, and if the smaller pipe be 2 inches and the larger 8 inches in diameter, then the relative positions are, as $\frac{2 \text{ representing the perimeters}}{4 \text{ representing the area}} = \cdot 5$ to $\frac{8 \text{ representing the perimeter}}{64 \text{ representing the area}} = \cdot 125$, which is only a fourth of the former, and as the quantity in the large pipe is 16 times greater, it is found (if we adopt this view) that the effect of a rectangular bend in a 6 inch pipe is, that of subtracting ($\frac{1}{4}$ of $\frac{1}{39}$ of $\frac{1}{16}$) $= \frac{1}{2496}$ of the volume which would have passed through a straight horizontal pipe.

We may therefore conclude, thus far, that the effect of bends in large air channels, such as those of mines, is not material. On the contrary, it is easy to conceive that at very high velocities, such as those generated by pit explosions, the effect of bends must be very great.

END OF CHAPTER II.

The resistance of fluids in motion is, in fact, a term of so great importance, that in extended channels the conservation of force to which the final velocity is due is comparatively insignificant. In a mine, the height of whose ventilating column is 144 feet, the theoretical velocity is ($8 \sqrt{144} =$) 96 feet per second, whereas the actual mean velocity may not exceed 4 feet per second; but the height due to 4 feet in a second is only ·25 feet of column, being the 1-576th part of the actual column employed in this particular example.

CHAPTER III.—*No.* 17.

In reference to the question of the "gravitation of the air in the descending and ascending parts of the mine," see further on.

CHAPTER III.—*No.* 19.

The resistance is due to the expansion $L\,P\,V^2\delta$. (See ante, p. 349.)

CHAPTER III.—*No.* 21.

The investigation of the motion and resistance of horizontal currents is not, however, sufficient to meet the whole question.

CHAPTER III.—*No.* 24.—*Ventilating Column.*

We have no analysis of such admixtures of air, gases, watery vapour, &c., as occur in mines, and in the upcast shafts of mines, and can only, therefore, approximate to their actual constitution. The following remarks may, at all events, help to show the extent and nature of the alterations in question, and whether they can be neglected without material error, as directly affecting the ventilating column. We are to consider:—

1. The alteration caused by changes of temperature and of hygrometric condition in the volume and density of the air.
2. The effect of extraneous products upon the return current, whether those products be derived from the gases of the mine or from respiration.
3. The effects of the products of combustion, when a part of the return air is decomposed by passing over a furnace.
4. The effect, which I shall here regard as a special one, of introducing steam into a shaft.

In following out the investigation I shall take an actual case, where the mean temperature of the upcast shaft was 105° Fahr., the quantity of air which entered the downcast pit was 30,312 cubic feet per minute, and the quantity of coals consumed by the underground furnace was 3·11 lbs. per minute.*

* In the calculations which follow, I have not introduced the *mean* temperature of the downcast air, as an element; the object being simply to make certain terms of comparison between air at 32° entering a mine, and the same air issuing, as modified by the complex circumstances to which it has been subjected in passing through the mine and the upcast shaft.

I have adhered to the rate of expansion stated by Gay-Lussac, namely, the $\frac{1}{480}$ part for each degree of Fahrenheit above 32°, the calculations having been made previously to Regnault's more recent investigations, establishing $\frac{1}{491}$, or rather $\frac{1}{491\cdot5}$, as a more accurate measure of expansion above 32° Fh. $= \frac{1}{459}$ from Fahrenheit's zero. The relative results are not altered by the difference between the two.

Now, if no other alteration were to take place in the entering air excepting that due to expansion by heat, we could very easily determine the relative volumes at 32° and at 105° to be 30,312 and 34,922 respectively, and the relative densities to be as 1 to ·8680.

But the other influencing circumstances, of which mention has been made, must also be considered; and first, as to changes in the hygrometric state of the air.

The temperature of the air at the surface was 32°; the wet bulb of Mason's hygrometer was 31½°; the atmosphere was, therefore, very nearly saturated with vapour. In the air current of the mine, before it passed over the furnace, both thermometers stood at 53°, again showing a saturated state of the atmosphere. And here occur the two first terms of our enquiry.

The expansion of air by the difference of temperature from 32° to 53°, being 21°, allowing 1-480 part of expansion for each degree above 32°, is as 480 to (480 + 21 =) 501, or as 1,000,000 to 1,043,750, and multiply by 30,313, we have the enlarged volume of air at 53°, equal to 31,648.

Then for the expansion by moisture at 53° compared with 32°, the volumes being as the sums of the elasticities of air and vapour respectively, we have,

	Inches.
Elasticity of vapour at 32°	0·200
Standard height of barometer	30·
	30·200
And Elasticity of vapour at 53°	0·415
Standard height, as before	30·
	30·415

Ratios of volume 30·200 to 30·415, or 1,000,000 to 1,007,119, which, multiplied by 31,638 gives 31,863 as the resulting volume when corrected for the temperature and hygrometric state of the mine.

A spontaneous ventilation is capable of being excited by a difference merely in the hygrometric states of the entering and issuing air currents, such difference amounting sometimes to one equivalent to that which would be produced by several degrees of temperature; if *dry* air entered a mine at a certain temperature, and issued even at the same temperature, but *saturated*, the issuing volume would be a good deal lighter than the entering one.

We may next consider the product of respiration. A man produces very nearly a cubic foot of carbonic acid gas in an hour, and to form the carbonic acid abstracts the same volume of oxygen from the atmosphere. And if we assume for the example taken, that 300 persons are employed, an extra number being computed to allow for horses, candles, and lamps, then the carbonic acid produced by them is only 300 cubic feet in an hour, or 5 cubic feet per minute, representing 25 feet of atmospheric air, viz :—

	Cubic Feet.
Carbonic acid gas replacing the oxygen, ...	5
Nitrogen, ...	20
	25

(Also vapour from the lungs 6 grains per minute, from each man; insensible transpiration from the lungs 20 grains per minute, from each man; in all 26 grains per minute = 4½ lbs. troy, in 24 hours, but these products are too small to affect the general result.)

As regards the gaseous products of the mine; in the absence of correct information we must take them at something which may be regarded as an extreme, and with this object in view, I shall assume that an addition of $\frac{1}{40}$ part is made to the volume already found, by the light carburetted hydrogen that issues in the mine. I need scarcely remark that this proportion very greatly exceeds what is generally met with, but the result is, in some measure, qualified by the circumstance that, if on one side the volume and consequent velocity be increased, the density is on the other diminished.

As regards the product of combustion. Supposing 1 lb. of coal to require $2\frac{6}{10}$ lbs. of oxygen for combustion, then 3·11 lbs., of coal will require 8·09 lbs. of oxygen. Some theory enters into the consideration of the products of the combustion of coal, but allowing the oxygen of the coal to form watery vapour with a portion of its hydrogen; and the nitrogen of the coal to form ammonia with another portion of hydrogen; the sulphur of the pyrites to leave in the shape of sulphuretted hydrogen, we shall then have the following products of combustion by weight:—

Watery vapour, ...	1·45 lbs.
Ammonia, ...	0·07 „
Sulphuretted hydrogen, ...	0·04 „
Carbonic acid, ...	9·64 „
	11·20 lbs.

(Coal, ...	3·0
Oxygen,.....	8·09
	11·20)

The first three ingredients are too minute in quantity appreciably to effect the result, and I shall, therefore, leave them unnoticed. The carbonic acid represents a volume which, at the temperature of the mine, would be 95 cubic feet.

We can now classify the several ingredients as follows :—

				Density.
Air entering the mine, ...			30,312 ..	1,000
The same for expansion to the temperature of the mine more, ...			1,326	
The same for the difference between the hygrometric state of the mine, and that of the atmosphere, more,			225	
			31,863	
Deduct air of respiration, ...		25		
Do. air required for combustion, ...		476	501	
			31,362 ..	·970
Add light carburetted hydrogen, which appears to be always mixed with other gases, as olefiant gas and nitrogen; specific gravity say 0·600, ...		Density.	784	
Add carbonic acid gas from respiration,	5 ..	1·548		
Do. from combustion, ...	95 ..	1·548	100	
Add nitrogen from respiration, ...	20 ..	·986		
Do. from combustion, ...	381 ..	·980	401	
			32,647	

In cases of ordinary combustion, a quantity of combustible matter escapes without being burned, a part of it appearing in the shape of smoke or soot. The carbonaceous particles which thus escape, however, easily float in air, owing to their minute division, and if converted into *invisible* carbonic acid by union with oxygen, act more in retardation of the current. By assuming them to be converted into carbonic acid gas (as in the calculation), a greater allowance is really therefore made than is due to them in an uncompounded state. In fact, the whole quantity

of coal consumed is only 3·11 lbs. per minute, and assuming 2½ lbs. to consist of carbon, and one-half of this to escape combustion, the quantity so escaping combustion becomes 1¼ lb. per minute.

Now, we shall see immediately that the aggregate quantity of air and other gases passing through the upcast shaft is 36,035 cubic feet, and that the common density of the mass is ·8724.

The weight of a cubic foot of such mixed gases, at this density, is ·0706 lbs., therefore the weight of 36,035 cubic feet is 2544 lbs. It is, therefore, manifest that the unconsumed carbon, being on the data assumed less than the $\frac{1}{2000}$ part of the weight of the entire volume can have no appreciable effect on the calculation.

We have next to calculate the densities, assuming that of the entering air to be 1. The rest are corrected to 53°.

Volumes.		
31,362	Air in mine at ·970, ...	30,421
784	Carburetted hydrogen at ·600, ...	470·4
100	Carbonic acid at 1·548, ...	154·8
401	Nitrogen at ·986, ...	395·4
32,647		31,441·6

$$\text{Mean density } \frac{31,441·6}{32,647} = \ldots\ldots\ldots\ldots\ldots\ldots \; ·9630$$

Expansion of volume 32,647 from 53° to 105°.

$$480 + 21 = 501$$
$$480 + 73 = 553$$
$$\text{As } 501 : 553 :: 32,647 : 36,035.$$

$$\text{Ultimate mean density in shaft} \ldots\ldots\ldots \; ·9630 \times \frac{32,647}{36,035} = ·8724.$$

The results are therefore :—

Volume of air entering the mine, ...	30·312
Volume of air and mixed gases in the upcast shaft, ...	36 035
Density of air entering the mine, ...	1·
Density of air and mixed gases at mean temperature of upcast,	0·8724

Relative velocities of cold and heated volumes, supposing them to move in channels of same sectional area, 1 to $\frac{36,035}{30,312} = 1·18880$.

Relative squares of same velocities, 1 to 1·4132.

And the density being 1 to ·8724, and all other circumstances alike, the relative resistance is as 1 to (·8724 × 1·4132 =) 1·2329.

If, with a view to those mines which yield carbonic acid gas, and not fire-damp, we assume the fire-damp to be replaced, in the example, by 784 volumes of the former, which is a larger aggregate quantity (1-40th) than we may expect to meet with in practice, then the statement in page 356 will stand as follows:—

Volumes.		
31,362	of air in mines at ·970 density	30,421
784	carbonic acid at 1·545	1,214
100	do. as before	154·8
401	nitrogen	395·4
32,647		32,185·2

Mean density ..... $\frac{32,185·2}{32,647} = ·9858$

Expansion from 53° to 105°, as before, 32,647 to 36,035.

Ultimate mean density in shaft, $·9858 \times \frac{32,647}{36,035} = ·8931$.

The relative resistances are, therefore, in this case, as 1 to (·8931 × 1·4132 =) 1·2621.

We have thus seen how the ventilating column is affected by the gaseous products of the mine and of combustion, namely,

	Weight of Downcast Column.	Weight of Upcast Column.	Difference.
1. Pure air	10,000....	8680....	1320
2. Altered air, with carburetted hydrogen	10,000....	8724....	1276
3. Altered air, with carbonic acid	10,000....	8931....	1069

The numbers in the second column are the densities, as already found.

If, then, the motive column in the case of pure air be 132 feet, it is reduced in the second case to 127·6 feet, and in the third to 106·9 feet; and the velocities or quantities will be, *cæt. par.*, as the square roots of those numbers, viz.:—

$$\sqrt{132} = 11·5 \text{ or } 100.$$
$$\sqrt{127·6} = 11·30 \text{ or } 98·3.$$
$$\sqrt{106·9} = 10·34 \text{ or } 90·0.$$

In other words, where mines with furnace ventilation yield carburetted hydrogen gas, the result due to the uncorrected ventilating column must be multiplied by $\frac{98·3}{100}$; and where carbonic acid gas is the principal gaseous product of the mine, then that result must be multiplied by $\frac{90}{100}$

The question of the proper relative size of downcast and upcast shafts is capable of being illustrated from the foregoing considerations, limiting our investigations for the present to the postulate, that *the resistances of the two shafts shall be equal,* one of them being for this purpose varied in *size,* if found requisite to do so. I shall assume that the shafts are of equal depth: if otherwise, the expression for length can easily be introduced: and that the diameter of the downcast shaft is 10 feet; we are then to determine the proper diameter of the upcast as deduced from the data already furnished.

We have seen that in the first case put the relative resistances in the two shafts are as 1 to 1·2329: and to equalize this resistance, which is the object of investigation, we are to increase the size in the upcast in a certain definite proportion. But this proportion is not a simple one, having reference to the numbers given. On the contrary, it is clear that if the diameter of the upcast be increased, then the other conditions of resistance are affected at the same time. The area for example, augments as the square of the diameter; the velocity diminishes in a similar ratio; and the resistance, again, diminishes as the square of the velocity. On the other side, an increased diameter enlarges the surface of contact; so that by arranging the whole of these terms, we ultimately arrive at the following equation, expressing the ratio, namely:—

$$\frac{D^2 \times D^2 \times D^2}{D} = \frac{D^6}{D} = D^5 \text{ to } D'^5$$

And the ratios of the diameters thus become

As 1 : 1·2329 :: (D^5 =) 100,000 : (D'^5=) 123290

Where D and D' are the respective diameters.

Then for $\sqrt[5]{D'}$ the log. of 123290 is 5·0909279 ÷ 5 = 1·0181856, the natural number of which is 10·426 feet, which is the proper relative diameter of the upcast; equal to 10 ft. 5 in.; that of the downcast being 10 feet.

Summary of comparative results:—

	Diameter. Feet.	Ins.	Area. Sq. Feet.	Velocity of Current. Feet per Second.
Downcast	10	0	78·54	6·43
Upcast	10	5	85·37	7·035
Increase in upcast	0	5	6·83	·605

In the foregoing investigation, it is clear that we may substitute the squares of the volumes, for the volumes × squares of velocities: since

the velocities and volumes increase, *cæteris paribus*, in the same ratio. Then we have :—

	Velocity.		Density.		
Square of	30,312	×	1	=	918,817,344.
Square of	36,035	×	·8724	=	1,132,829,916.

Proportional resistance 1 to 1·233 nearly as before.

Or if q be the volume in the downcast assumed to be 1.
d the density in the downcast also assumed to be 1.
q' the ratio of the volume in the upcast.
d' the ratio of the density in the upcast.

Then the ratios of the diameters should be as 1 to $\sqrt[5]{\frac{q'^2 d'}{q^2 d}}$; but $q^2 d$ is = 1: therefore the ratios are as 1 to $\sqrt[5]{(q'^2 d')}$: or as 1 to the natural number of $\frac{\log. q'^2 d'}{5}$

It has been argued that upcast shafts should be made of a section much larger at the bottom than at the top; and the cone of a glasshouse, or the still more disproportionate structure of a dome, have been adduced as types of a more scientific form of shaft than the one we are in the habit of employing. We are now enabled to test the value of this principle by applying to it the foregoing formula.

Supposing the current of the same shaft which has furnished the example to have a temperature at the bottom of 160° F., which is 55° higher than its mean temperature, then the question is, what ought to be its diameter at the bottom, to equalize, as before, the resistances of the two shafts as regards this particular point of comparison.

We have seen that the air entering the downcast, expanded in the mine from 30,312 volumes to 32,647 volumes, and that its density under these circumstances was ·9630.

Then for the expansion from 53° to 160° :—

480	.....	480
21	.....	128
501		608

As 501 : 608 :: 32,647 : 39,619 volume in upcast.

Ratio of volumes 30,212 to 39,619, 1 to 1·30704.

$$\cdot 9630 \times \frac{32647}{39619} = \cdot 7935 \text{ density in upcast.}$$

Then $q^2 d' = 1{\cdot}307^2 \times \cdot 7935 = 1{\cdot}708 \times \cdot 7935 = 1{\cdot}3553$.

The Log. of which is ·1310354 ÷ 5 = ·0262071 whose natural

number is 10·622 = 10 feet 7½ inches, the required size of upcast shaft, being an increase of 7½ inches only in the diameter of the downcast.*

We shall now put the special case of a large admixture of steam with the current of the upcast.

Supposing the entering air to be in this case 60,000 cubic feet per minute, and the temperature to be 149°, then the volume of air and mixed gases before passing over the fires will be 64,622, and the mean density ·9630 on the data already given.

But as the temperature in the upcast is higher, the expansion will be proportionably greater, viz. :—

$$\text{As } \frac{480 \quad 21}{501} : \frac{480 \quad 117}{597} :: 64622 : 77{,}004$$

Whence we have the mean density in shaft

$$= \cdot 9630 \times \frac{64{,}622}{77{,}004} = \cdot 8081$$

4 steam boilers consuming coals at the rate of 3 tons per day each, require 18⅔lbs. of coal per minute, and supposing 7lbs. of water to be evaporated by each pound of coal, this gives 130⅔lbs. of steam per minute, equal to 914,666⅔ grains of steam per minute, and this distributed amongst 77,004 cubic feet per minute of air volume in the shaft gives 11·87 grains to a cubic foot.

By Dalton's Table we find that this quantity is computed to saturate a cubic foot (not at 149° but) at 82°.

Therefore the enlargement of volume by the admixture of the steam is as follows :—

Elasticity of vapour at 53°	0·415
Standard.....	30·
	30·415
Elasticity of vapour at 82°	1·07
Standard	30·
	31·07

* The upcast should, therefore, in the case put, be *practically*, a uniform cylinder of about 10 feet 6 inches in diameter, the diameter of the downcast being 10 feet.

I do not here attempt to exhaust the subject of the proper relative size of downcast and upcast shafts; in reality, the sectional area of an upcast shaft has, in furnace ventilation, a material influence upon its temperature, that is, upon its *power*; its resistance is, therefore, only one part of the question.

Then as 30·415 : 31·07 :: 77004 : 78,662

And the ultimate mean density is, (allowing for expansion of vapour) $\Big\}$ $\cdot 8081 \times \frac{77,004}{78,662} = \cdot 7910$

It thus appears that the increased volume in the upcast, occasioned by the discharged steam, is no more than about the $\frac{1}{46}$ part, a difference not practically appreciable, especially when it is considered that the small increase of velocity, and, consequently, of resistance thus arising is met partly by the diminished density due to the same cause.

It is evident from the foregoing considerations that *the steam does not condense in the upcast, because there is not enough of it to saturate the volume of air with which it is mixed.*

*And as the steam retains its state of vapour, its latent heat is not given out during its passage through the shaft.**

If the air at 149° had been saturated with vapour, then the volume and density would have been as follows :—

Elasticity at 53°	0·415
Standard	30·
	30·415
Elasticity at 149°	7·23
Standard	30·
	37·23

As 30·415 : 37·23 :: 77,004 : 94,258.

Density allowing for expansion by

$$\text{Vapour } \cdot 8081 \times \frac{77,004}{94,258} = \cdot 6602$$

But to saturate a cubic foot of air at 149° requires 45·7 grains of vapour: therefore, 4 times the number of steam boilers would have been required for saturation.

CHAPTER III.—*No.* 25.

In estimating the pressure required to generate the final velocity, that velocity must not be regarded as the one existent at the top of the upcast

* The same quantity (by weight) of vapour, contains the same quantity of heat, whatever be the temperature of the vapour.

shaft, but as a mean velocity due to the passage of the air through an aggregate of channels, of which the upcast and downcast shafts are portions. The issue at the mouth of the upcast shaft is due to the momentum of the entire column; if reduced in area at the top the velocity would be increased, and we should then appear, on the principle advanced by the author, to have a greater residuum of force, whereas it is obvious that there would really be a less one, quoad the additional resistance created by such contraction. I have closed 2-3rds of the area of an upcast shaft at the top, in the middle, and near the bottom (by means of a cradle), without causing a sensible difference in the quantity of air circulating in the mine; in this case, therefore, the velocity of issue at the top of the shaft would be trebled, yet the force establishing that velocity was obviously not greater, but manifestly less than with the uncontracted shaft, for the reason above given.*

Again, supposing the upcast shaft to be, not contracted, but enlarged, such enlargement would cause a diminution of the velocity of issue, and would, therefore, according to the author's view, exhibit a less residuum of force generating the velocity. Yet it is evident that no such diminution has occurred, but, on the contrary, an increase of the remainder force, owing to the reduced resistance due to the lower velocity.

The ventilating column of Hetton Colliery, in the case cited, is $900 \times \frac{167 \cdot 5}{502 \cdot 5} = 300$ feet of air at 211°. The velocity in the upcast shaft I make, by calculation, 32 feet per second, and the column due to this velocity is 16 feet, or in cold air the height of column is 13·6 feet, as given. But the mean velocity, which ought to be the basis of calculation, is, (though not given) probably no more than 4 or 5 feet per second; and if the last of those numbers, then the height of column due to it is ·39 foot, which, instead of the 1-16th part of the ventilating pressure, is no more than the 1·577th part of it.

Similar remarks are applicable to Tyne Main and Haswell examples. In the case of Tyne Main there is not 1-8th, but really less than 1-500th of the ventilating power employed in generating the ultimate velocity.

CHAPTER IV.—*Nos.* 30 *and* 31.

Here, again, we feel the want of experiments, enabling us to fix with

* In the case cited, the velocity of the upcast current, in the full sectional area of the shaft, was not more than 13 feet per second.

precision the laws of the lowering of temperature in upcast shafts. There is a tendency to establish a minimum temperature in the upper portions of those shafts, which it will be very difficult to blend with a general law applicable to their entire development. The cause of this tendency resides in the circumstance, that a heat which is not of itself considerable, compared with the usual atmospheric temperature, when communicated to the walls or sides of the shafts, is retained by those walls; and the temperature of the air-current, being influenced by it, does not, therefore, *continue* to diminish, on reaching this part of the shaft, according to the same law which prevails elsewhere. In some cases I have found very little variation in the temperature of the upper 40 or 50 fathoms of the air-current in upcast shafts.

CHAPTER IV.—*Page* 110.

It is not requisite to have the dimensions of the upcast shaft given to ascertain the horse's power exercised in furnace ventilation: the height of ventilating column, the quantity of air discharged, and the weight of a cubic foot of air, are alone required for this purpose. For example, the height of column in the Haswell case is 154·5 feet, the quantity of air is 94,900 cubic feet per minute, and the weight of a cubic foot of air at 62° is ·0767 lbs.

$$\text{Then, } \frac{94{,}900 \times \cdot 0767 \times 154\cdot 5}{33{,}000} = 34\cdot 08 \text{ horse power.}$$

CHAPTER IV.—*Page* 112.

The question between furnace and engine ventilation requires much further research. The simplicity of the furnace, and its constancy of operation, are greatly in its favour; but its mechanical results are not relatively advantageous, and it is probable that, if the method of splitting the air had not been introduced, we should long ago have been obliged to supersede the furnace by mechanical agents of ventilation. I shall here make a comparison between the useful results of furnace and mechanical ventilation. The case taken is one from my own notes—that of Seghill Colliery, where there was not an underground steam engine, as in the case of Haswell, and where the result, as an example of furnace ventilation, is above the average relatively with the fuel consumed; the quantity of air being 42,708 cubic feet per minute, the coals consumed

4·70 lbs. per minute, the mean temperature of the upcast 122°, and the ventilating column 65·3 feet, equal to almost exactly 5 lbs. on a square foot. The horse power is, therefore,

$$\frac{42{\cdot}708 \times 5}{33{,}000} = 6{\cdot}47.$$

Now, allowing, as the author has done, 12 lbs. of coal per hour per horse power, (which is too much,) we have $\frac{6{\cdot}47 \times 12}{60} = 1{\cdot}294$ lbs. of coal per minute, due to the useful effect, which is in this case, therefore, only $\frac{1{\cdot}294}{4{\cdot}70} = 27{\cdot}5$ per cent. of the gross power in operation.

I am informed, by Mr. Samuel Dobson, of Treeforest, Glamorganshire, that a Struvé's Ventilating Machine, at the Middle Duffryn Colliery, did its work very well; and that the aggregate quantity of air, as found by experiment, in circulation through the mine channels, was quite equal to 5-6ths of the calculated quantity due to the machine, as deduced from the area of the cylinders and the number of strokes in a given time. It further appears, that the pressure required to open the valves of the machine was equal to 5-20ths of an inch of water, or 1·28 lbs. on a square foot.* Considering, then, this machine to be applied under circumstances similar to those of the furnace already calculated, we have,

$$\frac{\frac{6}{5}\,42{,}708 \times (5 + 1{\cdot}28 =)\ 6{\cdot}28}{33{,}000} = \frac{321{,}850}{33{,}000} = 9{\cdot}75 \text{ horse power;}$$

and $\frac{9{\cdot}75 \times 12}{60} = 1{\cdot}95$ lbs. of coal per minute, instead of 4·70, the furnace consumption.

$$\text{Then, } \frac{1{\cdot}294}{1{\cdot}95} = 66{\cdot}3 \text{ per cent. of useful effect.}$$

This inferior result with the furnace, as compared with the steam ventilating machine, is not perhaps difficult to be accounted for. Viewing the upcast shaft as a machine, the energy of which depends upon the temperature of the contained air, it is clear that the structure of the shaft is unfavourable to the conservation of that temperature, on account of

* This machine is the largest of the kind which has yet been erected—it has two 20-feet cylinders, and a double action; stroke may be made 4, 6, or 8 feet. With one cylinder at work it was driven twelve strokes per minute, 6-feet stroke. The estimated duty is, in this case, 45,200 cubic feet per minute, and the quantity actually in circulation in the mine was 38,000 to 39,000 cubic feet per minute. With two cylinders and 8½ strokes, the estimated quantity is 61,000 cubic feet; the actual quantity was 55,000 to 56,000 cubic feet.

the distance of its upper portions from the heating agency, and the absence of any means or appliance to maintain the original heat. It thus happens that the useful effect is governed more by what takes place in the shaft than by the original quantity of heat produced.

To augment the quantity of air multiplies the disadvantages of the furnace. Supposing that it were wished to double the quantity, we should then require eight times the fuel, or, in the case cited, 37·6 lbs. per minute, all other circumstances being the same. With machinery we should also require eight times the power, because the double velocity takes four times the power, and the moving power would also itself have to increase its velocity to twice the former rate; but this octuple ratio is attained at an expense of (1·95 × 8 =) 15·6 lbs., so that the comparison would stand as follows:—

Volume of Air.	Fuel, with Furnace. lbs.	Fuel, with Machine. lbs.	Difference. lbs.
1	4·7	1·95	2·75
2	37·6	15·60	22·00
Increase, lbs. per min.	32·9	13·65	

The furnace system has, in fact, been maintained by reducing the resistance; in other words, by carrying the splitting of the air to an extent of subdivision which, in some cases, can hardly be considered safe.

CHAPTER V.

Some years ago, Mr. J. Taylor made, at my request, upwards of one hundred observations at Haswell Colliery of the quantities of air circulating in the several splits (*then* eleven in number), with the areas and velocities at each point of observation. At that period the total quantity of air was 65,641 cubic feet; the mean temperature of the upcast was 109°; the ventilating column was 103·7 feet; the pressure 8·162 lbs. on a square foot, of which 4·92 lbs. were employed in ventilating the mine, and 3·24 lbs. in overcoming the resistance of the shafts.

Subsequently the quantity of air was increased to 94,900 cubic feet per minute; the ventilating column being 154·5 feet: the pressure on a square foot 11·90 lbs., of which 2·94 lbs. was employed in ventilating the mine, and 8·96 lbs. in overcoming the resistance of the shafts, including that of the short channels between the shafts and shaft doors.

The resistance of the mine channels was, therefore, less with the larger quantity of air than with the smaller one; the reason of which was, that

in the interim the number of splits had been increased from 11 to 18.

But the resistance in the shafts had, as a consequence of the increased volume of air, become much greater, and indeed absorbed not less than 75½ per cent. of the entire motive column. It is right to remark, that the size of the upcast shaft had, in the meantime, been partially reduced by casing the tubbing.

The enlargement of shafts, of which this result is at once suggestive, is not, however, to be regarded as a simple question. With an equal quantity of fuel, we cannot, *cæt. par.*, have the same temperature in a shaft of large area as in a smaller one, because the cooling power of the shaft depends greatly upon the expression $\frac{S}{V}$; if, then, the advantage gained by diminishing the shaft resistance be not commensurate with the disadvantage of the loss of motive column, or the necessity of using a greater quantity of fuel to make good that loss, we may lose and not gain by increasing the size of an upcast shaft; it follows, therefore, that there is a maximum size of shaft, having relation to the development of the mine channels, beyond which we should find the quantity of air per lb. of coal diminishing and not increasing. These remarks apply to furnace ventilation only; where machinery is employed, it is obvious that the larger the size of the shafts the greater is the useful result.

From the Haswell experiments, above referred to, I deduced the following theorem:—

$$V = 51{\cdot}11 \sqrt{\frac{HA}{LP}}$$

Where V is the velocity in feet per second.

H the height of ventilating column in air at 60°.

A the area or cross-section of air channel (or sums of the areas of the several channels).

L the length of channel.

P the perimeter of channel (or sums of the perimeters of the several channels.)

(Dimensions in feet.)

A theorem, from experiments by Mr. George Greenwell, at Crook Bank Colliery, differed from the foregoing. It was,

$$V = 38{\cdot}33 \sqrt{\frac{HA}{LP}}$$

Péclet's theorem for brick chimneys, when reduced to the same terms, is,

$$V = 36{\cdot}01 \sqrt{\frac{HA}{LP}}$$

CHAPTER VI.—*No.* 58.

Ventilation of Deep and Rise Workings.

I found, in some experiments on this subject at Earsdon Colliery, that when the deep-way was shut off, the loss of air was nearly one-half (46 per cent.) of the entire volume in circulation, with both rise and deep-way open; but when the contrary course was adopted—that of shutting off the rise-way, and keeping the deep-way open—the loss was only 1-6th (17 per cent.) of the entire volume in question. The air-channels in each way were very similar, both in length and in other respects; the inclination in the deep workings (towards the 90 fathom dike) averaged 1 in 6; in the rise-workings it was much less, being about 1 in 12.

The greater comparative facility with which deep workings are ventilated, is not, it is submitted, to be accounted for on a principle of *gravitation.* Setting aside considerations of temperature, variation, and other extraneous conditions, the weight of column *below* the level of the upcast is balanced by its return column *up* to that level. In the opposite case, if an *ascending* column of air be regarded as reacting against the ventilating power, its corresponding return column operates in favour of that power, and again neutralises the action. The barometric pressure doubtless alters with every step in an ascending or descending direction; but the mean result of all the heights in the ingate is equal to the mean result of all the heights in the return, *considered with a view to gravitation alone.*

There is another circumstance in which, I apprehend, a solution of the matter will be found to reside.

If a barometer be carried from the bottom of a downcast shaft, *upon the same plane,* through the ingate and return air-courses, it will be found constantly to *fall* in receding from the downcast and approaching the upcast. The difference in height represents, in fact, the pressure employed or absorbed in ventilating the mine from the bottom of the downcast to the point of observation, whether the latter be at the upcast shaft, or at any intermediate part of the air-course.*

* Of course a water-guage gives a similar result. I have made use of shaft doors and also of in-bye doors to determine the differences of pressure, allowing for the friction of the doors, as determined by experiment. A well-constructed door is, in fact, a pressure-guage, whose accuracy is proportional to its area: an error, if any exist in the experiment, being of relatively minor consequence when spread over so large a surface.

We have in this case supposed the barometer to be carried upon a water level line: but it is obvious that the same cause and its corresponding effect are in operation on ascending and descending planes, though the variations of the barometer due to simple differences of level render it in the latter cases less easy of detection.

The result then, is, that the entering air (starting from the bottom of the downcast) is in a state of greater compression than the issuing air; and as a direct conclusion, *that the air in the ingates is, owing to the cause assigned, and all other circumstances being alike, heavier or denser than the air in the returns.*

The consequences of this difference may be more clearly appreciated by supposing the return column to consist of a gas a little lighter than atmospheric air, or of a mixture of atmospheric air, and sub-carburetted hydrogen gas: and we shall then perceive that the lighter column ascends from the deep workings upon the same principle, in fact, that light or rarefied air ascends a shaft: but in the rise workings the operation is reversed: the lighter column if the return is to be *forced* downwards, and these cause a loss of motive column equal to the mechanical effort required for this purpose. It will be observed that in carrying out the comparison the result is doubly in favor of deep workings; for a positive addition is made to the power by which they are ventilated by the cause under consideration; while by the same cause an abstraction is made from the power ventilating the rise workings. The difference, therefore, is not measured by a simple expression (n) but by (n + n′) where n is the ascensional force assisting the return of the deep air, and n′ that retarding the return of the rise air.

I regret to differ from the author in my explication of this curious subject. Much stress is laid by him upon the supposed insignificance of the forces thus brought into operation; but those forces are in reality far from being insignificant, *relatively with the ventilating powers employed,* which is of course the only correct standard of comparison.

For example: supposing the ventilating column to be equal to 4 inches of water, of which 1 inch is employed in occasioning the resistance of the upcast; then at a medium distance from the downcast we shall have a residual pressure of $2\frac{1}{2}$ inches, and the mean compression operating upon the entering air is $\frac{4 + 2\frac{1}{2}}{2} = 3\frac{1}{4}$ inches; while the mean compression operating upon the return air is $\frac{2\frac{1}{2} + 1}{2} = 1{\cdot}75$ inch. The difference between the two is 1·50 of an inch.

Now, it is true, that this inch-and-a-half of water column cannot affect more than about the $\frac{1}{260}$ part of alteration in the *density* of the atmosphere; but it is *not* the density of the atmosphere which is the subject of comparison, the real question is, what proportion the *little water column of* $1\frac{1}{2}$ *inch bears to the ventilating column of the mine;* for just so much of that ventilating column must be employed in equalising the density, or in other words in forcing the return air down a descending plane; while on an ascending plane the result is exactly the reverse.*

The foregoing principles involve a yet undetermined point in mining—the proper situation of the ventilating shafts. If the air of workings to the deep of an upcast shaft be more easily conveyed to that shaft than air to the rise of it, then we are not in doubt as to the abstract principle which governs the right position of such a shaft. We might even go a step further, and affirm, that if the question were one of *machinery* employed in ventilating mines, then *that* machinery (for exhausting the air) ought to be placed at the extreme rise. But furnace ventilation is of a more complicated character, because an element of the ventilating column is depth of shaft. I trust to be prepared, in a short time, to bring this subject at large before the Institute, and shall not, therefore, carry my present notes further, especially as they have already extended much beyond my original intention.

* The case put is, of course, only for illustration.

NORTH OF ENGLAND INSTITUTE

OF

MINING ENGINEERS.

ANNIVERSARY MEETING, THURSDAY, AUGUST 2, 1855.

NICHOLAS WOOD, ESQ., PRESIDENT OF THE INSTITUTE, IN THE CHAIR.

The Secretary having read the minutes of the last meeting,

The PRESIDENT, after the proceedings of the Council had been read, briefly called attention to the recommendation of the Council as to the propriety of the members of the Institute giving their support to the intended Museum at the Coal Exchange, London. The Council recommended that mineral specimens, and other objects of interest, should be forwarded to the Coal Trade office for transmission to London.

Several new members were then proposed for election at the next monthly meeting; and one gentleman, viz., Mr. Benjamin Plummer, was duly elected a member.

The PRESIDENT said, that he had just received a letter from Mr. Matthias Dunn, in which that gentleman presented to the Institute his two works on the History of the Coal Trade, and a Treatise on the Mining and Working of Coal. He (the President) begged, in acknowledging Mr. Dunn's gift, to move a vote of thanks to that gentleman.

The motion, on being put, was carried unanimously.

The PRESIDENT next called attention to the propriety of the Institution being furnished with all the Reports published of the Inspectors of Mines.

Mr. DUNN said, that there were three separate Reports published. If

they passed a resolution, it might be forwarded to Sir George Grey, and perhaps they had better ask for more than one copy of each Report.

Mr. HUGH TAYLOR, Chairman of the Coal Trade, thought the Reports of considerable interest to the Coal Trade; and suggested that as many copies as could, should be obtained, with the object of diffusing the information they contained to all connected with the trade.

The PRESIDENT then submitted the following resolution on the subject:—"That application be made to Sir George Grey, Secretary of State for the Home Department, requesting him to favour the North of England Institute of Mining Engineers with copies of the Reports of the several Inspectors of Mines, from the period of their appointment under the act," which, being put to the meeting, was carried unanimously.

The PRESIDENT then referred to Mr. Atkinson's paper, and suggested that, as the original paper, together with the abstract, and correction of some errors would be printed in this year's volume of Transactions; he thought it would be desirable to print Mr. Taylor's observations likewise, in order that the whole might be discussed together. The whole subject being thus placed before them, they might then fix a day for the discussion of it.

Mr. ATKINSON thought that would be the best way, as members would have an opportunity of considering any doubtful or disputed points.

Mr. T. J. TAYLOR said, that if the meeting consented, he would put his remarks forthwith into the printer's hands.

After a few words from Mr. BOYD, approving of such a course, Mr. Taylor's remarks on Mr. Atkinson's Paper, entitled "Observations on the Theory of the Ventilation of Mines," was, after some discussion, ordered to be printed with the volume of the Institute's proceedings for the present year.

Mr. T. J. TAYLOR then read a paper, entitled an Account of the Performance of a Ventilating Machine,* on Struvé's Principle, at Middle Duffryn Colliery, North Wales, by Mr. Samuel Dobson.

At the termination of the reading of this paper a brief discussion ensued, which ended in several questions having been agreed to be submitted for Mr. Dobson's consideration, for the purpose of throwing some light upon a few unexplained points in the paper, and it was arranged that the paper should be brought before the Institute at their next meeting.

* See Volume IV.

The SECRETARY then read the Finance Committee's Report, and

Mr. T. J. TAYLOR read the General Report of the Institution for the past year.

Mr. TAYLOR then drew the attention of the meeting to that part of the Report having reference to the Fossil Flora Collection of Mr. Hutton, comprising the specimens used in getting up the Fossil Flora Publication of Messrs. Lindley and Hutton; and, in doing so, observed that the collection in question was at present in Newcastle, and in the hands of a private individual who was willing to dispose of them. The gentleman, however, had been in treaty with some parties without success, but at present there was an application from the Coal Exchange, London, and a bargain was likely to be struck for them. He, for one, thought it desirable to retain them in that part of the country, as they unquestionably were the best collection of the kind ever made connected with their own coal fields, and would serve to illustrate standard works on the subject. At the last meeting of the Council the subject was fully discussed, and every one present thought it desirable to secure the collection, if it could be obtained at a moderate cost, and consistent with the rules of the Institute. There were several hundreds of specimens, which, it was stated, would cost £140, the whole being within ten or twelve cases, which would cost other £20, making altogether the sum of £160. He knew that some doubt at first existed as to whether the funds could be applied for such a purpose, but after examining the rules the Council could not perceive that it would be improper to do so, especially as rule 10 set forth generally that the funds were placed at the discretion of the Council to dispose of. Under these circumstances the Council resolved to leave the matter for the general meeting to decide, as to whether the collection should be purchased or not? At one period it was in contemplation to purchase them by the contributions of individuals, with the ultimate view of presenting them to the Institute, but after all it was considered a better course to make the purchase at once, provided the terms could be arranged.

The PRESIDENT thought it would be a great pity to let the specimens go out of the district, especially as they were looking forward to the establishing of a Mining College, in which case the collection would be extremely valuable.

Mr. HUGH TAYLOR fully coincided with the propriety of obtaining the collection in question; but before the Institute could purchase, the first thing to be decided was, had they power to apply the funds to such

an object. If they thought they had, then they could not do better than at once close a bargain for the collection, which was invaluable. It was well known that Mr. Hutton was one of the first geologists of that county; and, in his opinion, the collection might legitimately be termed a "stone book!"

After a few observations from Mr. ELLIOT and Mr. BOYD in favour of the motion, the following resolution was proposed and agreed to:—

"Resolved—That a purchase be made of the Fossils of the coal formation used in illustrating the Fossil Flora of Messrs. Lindley and Hutton, provided the Council approve of it on inspection of the Fossils, and can procure the same at a sum not exceeding £140, exclusive of the cost of the cases containing them."

Mr. MATTHIAS DUNN said, he had then great pleasure to propose a resolution, which, he felt confident, would be unanimously adopted; it was, "That a vote of thanks be given to the President and Vice-Presidents and other Officers of the Institute, for the able manner in which they had conducted the affairs of the Institute during the past year."

Mr. HUGH TAYLOR having seconded the motion, it was carried by acclamation.

Some conversation next ensued relative to the propriety of changing the hours of assembling at the respective monthly meetings, many members expressing it as their opinion that it would be better to alter them. Ultimately the following motion was made and agreed to on the subject:

"Resolved—That in future the meetings of the Council, preparatory to the General Meeting, shall be held at 12 o'clock, and the General Meetings at 1 o'clock on the respective days of meeting, instead of 1 and 2 o'clock respectively as heretofore."

A vote of thanks was also passed to Edward Boyd, Esq., and other members of the Finance Committee, for the able manner in which they had conducted the financial business of the Institute.

The meeting afterwards broke up, when the members present, together with several other gentlemen, dined together at the Queen's Head Hotel in honour of the third anniversary of the Institute.

NEWCASTLE-UPON-TYNE: PRINTED BY ANDREW REID, 40, PILGRIM STREET.

AN ABSTRACT OF THE ALPHABETICAL LIST

OF PITS IN MR. T. Y. HALL'S PAPER *

ON THE

GREAT NORTHERN COAL FIELD,

SHEWING THE

NUMBER OF COLLIERIES TO BE ABOUT 136,

NUMBER OF FIRMS TO BE ABOUT 90,

NUMBER OF PITS FOR SEA SALE TO BE ABOUT 200,

FOR SHIPMENT AT THE UNDER-MENTIONED PORTS IN DURHAM AND NORTHUMBERLAND, VIZ :—NEWCASTLE, SHIELDS, SUNDERLAND, SEAHAM, MIDDLESBRO', COWPEN OR SEATON SLUICE, BLYTH, AND AMBLE NEAR WARKWORTH.

1854.

H household; S steam; G gas; C coke; CG coke and gas; CH coke and household; HG household and gas; HGC household, gas, and coke.

LADY F. A. VANE LONDONDERRY.

NAMES OF PITS.	NAMES COALS SELL BY.	
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2 Alexandrina, Lady Vane L.	Eden Main	H
10 Broomside, Lady Vane L.	Pensher W.E.	H
112 Lady Seaham Pit, Lady V. L.	Stewart's Steam	S
122 Meadows, Lady Vane L.	Seaham W.E.	H
128 Old Durham, Lady Vane L.	Old Ducks	H
134 Pensher, Lady Vane L.		
135 Pittington, Lady Vane L.	Nut Coals, Bean Coals, Small Coals	
140 Rainton Pits, Lady Vane		
141 Resolution Pit, Lady Vane		
143 Seaham, Lady Vane L.		

EARL OF DURHAM.

11 Brass-side, Earl of Durham	Lambton W.E.	H
99 Houghton-le-Spring, Earl of Durham	Lambton's Primrose	H
	Frankland W.E.	H
109 Little Town, Earl of Durham		
111 Lady Durham Pit, Earl of D.	Steam Boat Hartley	S
126 Newbottle, Earl of Durham	Little Town W.E.	H
145 Sherburn, Earl of Durham	Newbottle	H
146 Sherburn House, Earl of D.	Ditto	S
149 Shadforth, Earl of Durham	Nut Coals, Bean Coals, Small Coals	

*See Volume II.

HETTON COAL COMPANY.

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116 Mount Moor, J. B. and Co.	Mount Moor ..... H
156 Springwell, J. B. and Co.	Peareth . ..... H
104 Killingworth, Do.	Wharncliffe Wallsend..... H
151 Seaton Burn, J. B. and Co.	Killingworth Do. ..... H
57 Delight Pit, Do.	Ravensworth West Hartley .. H
136 Peareth Old Pit, J. B. & Co.	

NICHOLAS WOOD.

13 Black Boy, or Tees W.E., N. Wood	Tees W.E. ..... H
	Tees Hartley—Splint ..... H
Coundon, T. W. E., N. W.	Coundon W.E. ..... H
108 Leasingthorne, T. W. E, N. Wood	Leasingthorne W.E. ..... H
195 Westerton, T. W. E., Nich. Wood	Bishop's Tees ..... H

W. BLACKETT, N. WOOD, ANDERSON, AND PHILIPSON.

87 Harton, St. Hilda and Jarrow	Harton, St. Hilda, Jarrow .... H

THORNLEY COAL COMPANY.

Thomas Wood, Gully, Chaytors, Burrell.

107 Ludworth, Thornley Co.	Ludworth W.E. ..... H
174 Thornley Coal Company's Pits	Thornley ..... HG
	Ditto . .. . CG
163 Trimdon, Thos. Wood, Gully, and Burrell	Harvey ..... CG
	Trimdon W.E..... H

JOS. PEASE, JOSEPH WHITWEL PEASE, & JOS. PEASE & CO.

NAMES OF PITS.	NAMES COALS SELL BY.	
4 Adelaide Shildon, J. Pease	Adelaide W.E.	H
59 Deanery, J. Pease	Deanery W.E.	H
24 Bowden Close, J. W. Pease	Bowden Close U.S.	C
69 Eldon, J. and H. Pease	Eldon W.E.	H
94 Hedley Hope, J. Pease	Hedley Hope U.S.	C
102 Jobshill, J. Pease	Jobshill	C
138 Roddymoor West Pits, J. P.	Pease's West W.E.	C
139 Roddymoor East, Do.	Roddymoor East	C
159 St. Helens, J. Pease	St. Helens W.E.	H
191 Woodhouse Close, Sir Charles Maclean coals, wrought by Mr. Heckless for J. Pease	Clavering's W.E.	H
	Woodhouse Close	H

EDWARD RICHARDSON & CO.

5 Acorn Close or Charlaw, E. R.	Acorn Close W.E.	H
43 Cresswell, Anfield Pl., E. R.	Cresswell	H
54 Castle Pit, E. R.		
56 Derwent, E. R.	Elm Park	H
70 Eden, E. R.	Eden W.E.	H
117 Medomsley, E. Richardson	Medomsley	H
154 Spital Tongues, E. R.	Spital Tongues	H
123 Medomsley Old, J. Richardson Langley	Old Medomsley	C

JAMES JOICEY.

31 Beamish, Joicey	Beamish South Moor Main	H
161 Stanley East, Joicey	Beamish Unscreened	H
169 Twizell, Joicey	New Pelton Main	C
165 Tanfield East, Joicey	Old Tanfield	C
171 Tanfield Lea, Joicey	Bute's Unscreened Moor, Lady Windsor's Tanfield, Windsor's Pontop, Simpson's Pontop	H
170 Tanfield Moor, J.	Tanfield Moor, South Pontop	C
173 Tanfield South, J.	South Tanfield W.E.	C
	Ditto Unscreened	C

STELLA COAL COMPANY.

EXECUTORS OF THE LATE J. BUDDLE—T. Y. HALL, CHAS. & ADDISON POTTER, & M. W. DUNN.

172 Townley West, Stella Coal Co., Whitefield	West Townley W.E.	H & CG
	Ditto U.S., Whitefield	C
175 Townley Stella Coal Company Freehold Pit	Stella W.E.	H & CG
	Townley Glebe	CG
176 Townley Glebe Pit, Do. ; off	Stella Coal Co., W.E.	H & CG
177 Do. East, Emma Pit, Do.	Small Coals	

ROBSON AND JACKSON.

NAMES OF PITS.	NAMES COALS SELL BY.	
17 Binchester and Newfield	Newfield	C
21 Byer's Green	Byer's Green W.E.	C
35 Bowburn	Ditto U.S.	C
39 Clarence Hetton	Bowburn	C
40 Crowtrees	Clarence Hetton W.E.	H
48 Coxhoe, or Kelloe	Crowtrees W.E.	H
92 Heugh Hall	So. Kelloe, Coxhoe Do. WE.	H
95 Hetton West	Heugh Hall W.E.	H
98 Hunwick Pit	West Hetton W.E.	H
	Hartley W.E.	HG
	Ditto U.S.	C
53 Little Chilton, J. R., Mangr.	Little Chilton W.E.	H

R. P. PHILIPSON.

37 Cassop, Philipson	Cassop W.E.	H
38 Cassop Moor, Philipson	St. Cuthbert's W.E.	H

MESSRS. CARR AND PARTNERS.

32 Burraton, Carr and Co.	Burraton	HG
41 Cowpen, Carr and Co.	Cowpen	S
83 Hartley, Carr and Co.	Felling U.S.	G
153 Seghill Pits, Carr and Co.	Carr's Hartley	S
72 Felling Pit, Carr, Potts, & Co.	Seghill	S

Earsdon, Messrs. Taylor	Earsdon W.E.	H
88 Holywell Old Wt., Plummer, Taylors, Clark, and Lamb	Holywell West	H
89 Holywell New East, Do.	Holywell East	H

42 Cramlington East Pits, J. Lamb, Potters, and Co.	West Hartley	S
152 Seaton Delaval, Lamb, Scott, Barnes, Burdon, and Co.	Seaton Delaval	S
183 Walbottle, J. Lamb, Potters, Jobling's Trustees	Hasting's Hartley	S
	Walbottle	H
	Holywell	HGC

167 Tyne Main, Losh and Co.	Tyne Main	G
73 Friar's Goose, Do.	Do.	G

74 Framwellgate Moor, J. Bell and Hunter	Framwellgate	CH

130 Ouston, Hunt and Co.	Ouston	CG
179 Urpeth, Hunt and Co.	Urpeth W.E.	CG
	Do. U.S.	CG

132 Pelton Moor, Swaby and Co.	Pelton	CG
	Do. U.S.	CG

CONSETT IRON COMPANY.

NAMES OF PITS.	NAMES COALS SELL BY.
44 Crook Hall, Consett I. Works	Used for Iron Works.
51 Conside	Do. Do.
52 Conside Pits, Iron Co.	Do. Do.

GEO. ELLIOTT, JONASSHON.

129 Oxclose, Elliott & Jonasshon	Oxclose W.E. ..... HG
178 Usworth, Elliott & Jonasshon	Usworth W.E. ..... HCG
125 Nettlesworth, E. and J.	Nettlesworth W.E. ..... HG

MESSRS. COOK AND CO.

45 Castle Eden Pit	Castle Eden..... H
	Do., Steam ..... S

MESSRS. HEDLEY'S.

47 Craghead, Hedley	Craghead ..... HG
93 Homeside, Hedley	Homeside ..... H

EXECUTORS OF MESSRS. BRANDLING.

81 Gosforth	Gosforth W.E. ..... H
55 Coxlodge, Bell and Brandling	Brandling Main ..... H
	Riddell's W.E. ..... H
	Coxlodge ..... HG

MR. TYZICK.

66 Edmondsley, Tyzick	Edmondsley W.E. ..... HG

DALTON AND CO.

84 Heaton, Dalton and Co.	Heaton W.B. ..... HG

MESSRS. EASTON AND CO.

131 Oakwellgate, Easton and Co.	Oakwellgate U.S. ..... G
85 Hebburn, Do.	Hebburn ..... G

J. B. PEARSON AND CO.

86 Heworth, J. B. Pearson & Co.	Heworth U.S. ..... HG
	Dean's Primrose ..... H
106 Kepier, Dixon Ralph	Kepier W.E. ..... H

COOKSON, CUTHBERTS, AND LIDDELL.

114 Mickley, by dayhole drift from surface, C., C., and L.	West Wylam W.E. ..... HC
	Mickley U.S. ..... HC
118 Marshall Green, Skinner	Skinner..... C
24 Netherton Pits, Birkinshaw's Trustees	Netherton ..... S

W. W. BURDON, W. BARKUS, JUN., AND CO.

8 Eighton Moor	Eighton Moor W.E. ..... HG
16 Broomhill, W. Barkus, Murray, and Burdon	Broomhill..... S
Allerdean, W. W. Burdon	Allerdean ..... H
36 Black Prince Pit, Attwood	Coal mostly consumed by their own Iron Works at Towlaw and other places
166 Thornley, Towlaw, A. and Co.	
168 Towlaw L. S. Pits, Attwood	
71 Elm Park	

NAMES OF PITS.	NAMES COALS SELL BY.
184 Wylam East, J. B. Blackett, M.P.	Wylam ..... HG Prudhoe Main ..... G
185 Waldridge, Sowerby & Co.	Waldridge W.E. ..... G Ditto U.S. ..... G
187 Whitworth, R. & J.	Whitworth W.E. ..... G Ditto U.S. ..... G
190 Witton Park and Witton, Kirsip	Witton Park C
192 Whitwell, J. M. Ogden	Whitwell W.E. ..... HG
193 Wingate Grange, Lord Howden	Howdon W.E. ..... H Caradoc W.E. ..... H
197 Walker, Lambert and Co.	Walker W.E. ..... H Pott's Primrose ..... H
SOLD TO JOSEPH & JOHN HARRISON IN 1854.	
137 Radcliffe Pit	Radcliffe ..... S
160 Stanley East, Burn & Co.	East Stanley ..... CG
180 Wingate South, F.	South Wingate ..... HS Ditto ..... S
STRAKER AND LOVE.	
19 Bitchburn South	Bitchburn C
23 Brancepeth	Brancepeth C
158 Willington or Sunny Brow	Willington C
BOLCKOW AND VAUGHAN.	
6 Auckland West, Bolckow & Vaughan	West Auckland C
67 Etherley New, B. & V.	Etherley New C
188 Woodifield	Wood Field C
194 Whitelee	White Lee C
	These mostly used for their own Iron works
HENRY STOBART AND CO.	
20 Bitchburn North, H. Stobart and Co.	North Bitchburn C
68 Etherley, Old, H. Stobart	Old Etherley C
MARQUIS OF BUTE'S EXECUTORS.	
76 Garesfield Co, Chopwell	Garesfield U.S. ..... GC

NAMES OF PITS.	NAMES COALS SELL BY.
9 Ashington, Harrison, Carr, and Co.	Portland Hartley ..... S
14 Backworth, Waldie and Co. 182 West Cramlington Pits, Waldie and Co.	Northumberland W.E..... H Backworth ... . H Buddle's West Hartley ..... S
DAVISON, EASTON, ANDERSON, STODART, BATES, AND HENDERSON.	
15 Bedlington Pits, D & Co.	Davison West Hartley..... S
34 Barrington Pits, Longridge	Longridge's West Hartley .... S Begbie's Hartley ..... S
26 Burnopflat, Sowerby & Robt. Fletcher	Burnopflat W.E..... HG Ditto U.S..... HG
28 Blaydon Burn, Joseph Cowen	Blaydon Burn ..... CG Ditto U.S..... CG
30 Blaydon Main, G. H. Ramsay	Blaydon Main ..... CG Ditto, U.S. ..... G
78 Evenwood, Armstrong	Evenwood..... HG Gordon ..... HG
157 Sacriston, W. H. Bell	Sacriston W. E. ..... H
22 Bitchburn New, Muschamp	New Bitchburn C
27 Bebside N. Pit, Lambert & Co.	Bebside..... S
18 Butterknowle & Copley Bent, Prattman's Trustees	Butterknowle ..... C Copley Bent..... G
115 Morpeth Banks Old Pit	
33 Burdon Main, Hope, landsale	Burdon Main C
79 Gordon West Old Pit	
75 Fenham Old Pit	Fenham ..... G
63 Elswick Old Pit	Elswick ..... G
64 Elswick Low Do.	Elswick Low ..... G
Wallsend pit, resumed at this time by Losh, Wilson, Bell, & Co.—Nov. 1854	Wallsend C

The iron ore districts alluded to are three in number, viz.:—one in Weardale, Durham, one in Ridsdale and Hareshaw, in Northumberland, and the third in Cleveland, on the coast, extends from west of Redcar southward beyond Roseberry Topping to Whitby, covered in many places by a large common of fine peat turf. This peat may hereafter become valuable for reducing the bulk and weight of the refuse stone from the iron ore, by roasting, to double its per centage, so that it may be shipped and conveyed at one-half the cost to the Tyne and other places where suitable coal and furnaces are found for smelting and manufacturing it.

RECAPITULATION

OF

COLLIERIES, FIRMS, PITS, AND WORKMEN;

ALSO THEIR PRODUCTIONS.

From the foregoing alphabetical list, also the list of pits, comprising about 136, of the several large as also small collieries, it will be seen that there are 192, or about 200 working pits, exclusive of landsale pits, which are considered of little account in this coal district. It is, however, well known that 10 or 12 out of the 192 mentioned have been off work during the past year; they are, however, partly made up again by divided shafts, making double pits, such, for instance, as at Haswell, Hetton, South Hetton, Thornley, and others; besides, we must add, instances of three or four new pits sinking, and which are about to commence working. The number may, therefore, at present be fairly estimated at 200*; but, as to the number of firms or lessees of collieries, these may be said to be less—say 80, deducting 10 off work, and these I could easily print in another list, without the names of the pits, but with the names of the collieries and the lessors, opposite each of the lessees, if the Council of this Institute deem such expedient. The above may be considered to be generally correct, yet, after all, it is possible for some error to have crept in—it cannot, however, amount to anything sufficient to affect the calculation herein submitted. The following table (made up from that on page 206†) shows the number of underground men and boys employed in one pair of pits, or a shaft divided, so as to make two pits, viz.:—Haswell, which in itself vended 200,000 tons in one year, and one of the single pits, the Emma, belonging to the Stella Coal Company, which vended 100,000 tons in one year. The statement, as under, will form a correct guide for the greater proportion of the remaining pits, and staff of underground hands:—

Abstract of Staff brought from page 103.	Hewers.	Safety Staff.		Off-hand Men.	Putters & Boys	Total.
		Men.	Boys.			
Haswell Pits	210	60	13	19	126	428
Emma, near Ryton..	98	19	8	9	45	179
	308	79	21	28	171	607

* Including ten or a dozen pits where feeders of salt water have been found, also, the like number where pent up gases have been found in cavities, and when those cavities are cut into, have, on account of the great pressure they had been confined at, come off in great force, then generally termed a *blower*.

† The figures in this and two following Pages refer to Vol. II.

These totals show that the work of each hewer, or cutter of coal, averages 1,000 tons annually, or 3¾ tons per day, reckoning 273 days for the year; but if the safety-staff, off-hand men, and boys be included, the average will then be only 494 tons annually. This estimate, however, excludes the men and boys engaged at the bank, or the top of the pits. It may here be further observed, that although the greater portion of coal in the northern coal field is more tender in quality than in the district in which the two pits alluded to are situated, the calculation given may still be relied upon.

If these bases be admitted, then we can easily estimate the grand total, as follows:—

By referring to Chapters XIX and XX, pages 203 and 204, it will be seen that the total vend in the year 1853 was 13,333,000 tons, and if we assume, for argument's sake, that the same vend will take place in 1854, and calculating the pits as heretofore stated, then the entire number of men and boys employed underground will be 26,977, giving an average of 140 hands for each pit, with an average quantity of coal produced at them of about 70,000 tons. But it must be recollected that, although the average is 70,000 tons, yet some of the collieries possess two, three, four, and even six pits, consequently, when we give the collieries as a whole at 136, the average of each colliery will be 100,000 tons instead of 93,681 tons, and 58,000 tons for one pit, as previously stated in page 102.* If, in addition, the working firms are estimated at 80, as some are not in operation at present, then the average of each firm will be about 166,625 tons. But, assuming the working pits to be dispersed uniformly over the 750 square miles of the northern coal field, that would only average about 3½ square miles for each pit; and, further, if those pits that are called landsale pits—as well as those others mentioned as being off work, but being resumed—would make the total 300, or more than the average, they would only give 2½ square miles for each pit. The old pits will all be available to a certain extent hereafter; and, as the 136 collieries, or 200 pits, are fit out with engines and all other necessary appendages, they show a very encouraging view of the coal district, only averaging 5½ square miles for each colliery. It cannot, therefore, in future be necessary to expend much capital in sinking more pits over this limited and circumscribed coal field. It will further be seen, by referring to pages 284 and 285, that twelve or sixteen of the largest of the present colliery owners hold in themselves one-third (or 200 square miles), leaving 550 square miles, which is partly worked out already, and part may never be worked; this will reduce the 750 square miles, and give an average for the remainder of the present collieries, viz. 120, of 3¾ square miles for each colliery or firm.

* When this low average was taken into account the 27 landsale pits were included. By reference to Chapter XX, pages 204 and 205, it will be seen that the Lancashire, Cheshire, and North Wales coal district requires 939 pits and day levels, with 31,950 underground workmen, to produce 9,923,000 tons yearly, making an average of each pit per day of 39 tons, or 10,558 tons yearly with 34 men—on an average each producing 311 tons, which leaves 1 1-7th to each collier per day. Scotland employs 22,250 men and boys for 7,250,000 tons—equal to 340 tons for each underground hand yearly. Lancashire and Scotland coal principally used for home consumption.

The total number of workmen at this time, 1854, may be divided thus:—

½ or 3-6ths..	13,500	hewers, averaging 1000 tons annually.
1-6th	3,300	safety-staff men.
	1,400	boys belonging to the safety-staff.
⅓ or 2-6ths	1,200	off-hand men, bargain work, &c.
	7,600	putters and boys.
	27,000	makes an average of 494 tons.

This also gives a very encouraging view of the state of the trade, and the advantages arising to the workmen from being better employed. For instance, if we refer to Chapter XVII, page 197, it will be seen that in the year 1844—and this statement is taken from a printed document—the total number of men and boys employed was 25,383, and the vend then produced 9,623,922 tons. If, therefore, the vend with the number of hands employed be compared with the vend and number of hands in 1853, it will clearly prove that the workmen could not have been fully employed in 1844, for, instead of producing no more than 9,623,922 tons, they ought to have produced 12,600,000, or more: besides, the average produce of the men and boys in 1844 was only 382¼ tons, while in 1853 it was 494 tons. Thus I find that the increase of underground workmen from 1844 to 1853 is not more than 2,000 altogether, which for nine years is only an increase of about 200. By taking into account the amount of work the 200 a-year extra hands could perform in the nine years, it shows that the same number of old hands in 1844 have evidently gone on gradually increasing per workman from 382¼ to 494 tons yearly, over a period of nine years; but if we take the work of the hewers alone, it will be seen that they averaged, in 1844, 764½ tons, while at the present time they average 1000 tons each *, rather more than 3¾ tons daily.

That gradual average increase will be seen as follows:—

In	1845	1846	1847 & 8	1849	1850	1851	1852	1853	1854
Hewers	790	618	842	868	894	920	946	970	996
Total underground hands, &c.	394	401	418	430	442	454	466	478	494

Notwithstanding, these statements being true, yet still it cannot be said that the men have arrived at a fair maximum of work, as they are quite capable of doing more, although both extra work and higher prices are given to them than in 1844. But it is also a surprising fact, that

* It must be recollected that, in the year 1844, the men commenced an obstinate strike, which continued for 19½ weeks; but ultimately they had to give in after enduring a great loss to themselves and families: while, on the other hand, the coal-owners suffered great loss through the strike, and at length had to introduce, at great expense, new hands from coal mines in Wales, and sundry lead mines and various other places.

the hewers generally prefer working for 4s. 6d. or 5s. per six hours, when they actually could earn 7s, in eight hours, when the demand for coals for shipment is great. If this disposition of the men be persevered in the consequence will be, that if the demand should hereafter increase, the workmen will either have to exert themselves, by breaking through the ill-advised rule they have adopted among themselves, or else they will find, in the end, that they will drive parties to get supplies at other distant districts; or, on the other hand, the coal-owners of Durham and Northumberland will be driven to resort to more mechanical means, or introduce a sufficient number of hands from a distance to work the extra quantity of coal required. If that be so, the probability will be, that some reduction in the quantity of work performed by each underground hand, that is, at piece work, will ensue, to the detriment of the present local workmen, as the extra hands or coal-cutting machines that may be brought into the coal pits in this field will tend to reduce the wages of the present local staff.

COAL-CUTTING MACHINE.

About a month ago the writer was down one of the pits belonging to the Earl of Balcarres and Crawford, in company with Mr. Peace, the manager, who is the inventor of a machine for cutting coal, worked by means of compressed air, with two 3½-inch cylinders, up to six-horse power—it was then finishing a piece of work it had been set to perform.

On applying the flexible air-tube, about an inch in diameter, between the small metal air pipe and the machine, it commenced cutting the coal, and completed a piece of work 200 yards long, 5 yards wide, and 4½ feet high, with wonderful alacrity, and without any visible means of producing so great a power.

The machine is very compact, being only about 3 feet long by 2 feet wide and 2 feet high. It is so constructed that it will either travel on the rails of the tub carriage-way, or on the sill of the mine, by means of castors which are made to work in any direction by a man pushing it. The cutters move forward by their own power, four feet in length, while the machine remains fixed.

The inventor is now making one of 10-horse power, which will be better adapted for general use, it being so finished as to cut the blocks better fitted for market: the former one cuts perpendicularly and underneath the coal four feet—dust waste very little—the width of the cut being two inches. Machine No. 2, like No. 1, is a complete and very strong piece of workmanship, being wholly of iron, metal, and brass, is also so adapted as to cut horizontally and vertically. This is a great advantage; and being worked by compressed air, the refuse considerably improves the ventilation of the mine.